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SLOW-RUSTING FORAGE OATS DEVELOPMENT AND RELEASE FOR SUBTROPICAL AUSTRALIA

DAQ.063

Preliminary Report

QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

Meat Research Corporation

CONTENTS

PART 1

Project Title: Slow-rusting forage oats development and release for subtropical Australia.

Project No. DAQ.63

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Objective

To select and release rust-resistant and slow-rusting cultivars of forage oats suitable for subtropical Australia.

Summary

A number of oat cultivars selected from field trials and cited in the literature, were screened in the glasshouse for partial resistance (PR) (slow-rusting) to *Puccinia coronata* f. sp. *avenae* (Pca). The technique developed to select for PR in the glasshouse involves inoculating the first or primary leaf of seedlings in a spore settling tower using approximately 10 mg of uredospores. Plants were incubated in a controlled temperature cabinet maintained at 23° $\pm$ 2°C and after 10 to 12 days, uredium density was recorded and compared to that of a susceptible cultivar.

Using this technique, two oats were identified as expressing PR. Panfive and 86QK-51 both expressed moderate levels of resistance when compared to Algerian (a highly susceptible cultivar) both in the field and in the glasshouse. Panfive appears to express a race specific PR, while 86QK-51 has remained resistant in the field during the past two years.

Attempts at breeding for PR were made by crossing Panfive with Ascencao and Pan 4 using a pedigree system. F_2, F_3 and F_4 lines of these crosses were screened in the field for resistance to Pca from 1990 - 1992. Nine resistant lines were selected from the field trials of the F_4 progeny while 17 lines were selected from glasshouse screenings of the F_3 progeny of the Panfive x Pan 4 cross. These lines have been taken up by Pacific Seeds Pty. Ltd. for further testing prior to commercialisation.

PART 2 EXECUTIVE SUMMARY

(i) Background and industry context

In subtropical Australia, oats are grown as a major winter forage crop with approximately 300 000 ha of oats grown in Queensland in 1988. Compared to wheat and barley, oats have a greater ability to regenerate after grazing and are therefore preferred. However, oats are susceptible to a number of rust diseases. In subtropical Australia, leaf or crown rust caused by *Puccinia coronata* f. sp. *avenae* (Pca) is one of the major diseases affecting oats. When oats are planted early in the season (February, March, April), build up of inoculum can occur early on. This inoculum is then present for a long period of time (May to October) during which conditions ideal for rust epidemics occur. The grazing potential of an oat crop may be reduced by up to 50% as a result of an epidemic as was the case in 1988 when much of southeast Queensland experienced a mild wet winter.

Although cultivars resistant to Pca are available, races of the pathogen capable of infecting these cultivars have appeared relatively quickly (ie. within 5 years). The nature of resistance in these cultivars has generally been complete ie. allowing little or no rust development. However, cultivars expressing slow-rusting (partial or incomplete resistance) may express a more durable resistance in the field due, in part, to the reduction in the selection pressure on the pathogen.

Following the terminology of Parlevliet (1979), partial resistance, the term adopted for this report, is " a form of incomplete resistance in which spore production is reduced, even though the host plants are susceptible to infection". By reducing the numbers of spores produced, inoculum build up will be slowed and the rate of an epidemic will be reduced (compared to that of a highly susceptible cultivar). In reducing the rate of the epidemic, a crop may be harvested or grazed before much damage has been done. It is for this reason and the premise of greater durability of the resistance that endeavours have been made to identify slow-rusting or partially resistant cultivars.

(ii) Project Objectives

The common occurrence of oat leaf rust epidemics in Queensland has prompted the search for partially resistant oat cultivars. It was therefore the aim of this research to:

1. To select and release rust-resistant oats cultivars prior to identification of slow-rusting characteristics and release of slow-rusting cultivars.
2. To screen oat cultivars in the glasshouse for slow-rusting characteristics.
3. To investigate the effectiveness of slow-rusting cultivars of oats in controlling crown rust in the field.
4. To investigate the mechanisms (eg. incubation period, number of pustules produced, etc.) which contribute to slow-rusting.

(iii) Brief methodolgy

Sources of partially resistant cultivars or lines

Candidate lines or cultivars for this project were sought through both field screenings and the literature. Field screenings of International oat lines conducted at the Queensland Wheat Research Institute (QWRI) Toowoomba, Qld, provided a source of slow-rusting material. This field screening site at the QWRI also provided a means by which any promising material could be screened in the field over a number of years while at the same time being investigated in the glasshouse.

Several cultivars cited in the literature as being slow-rusting, partially resistant or semi-tolerant were obtained from the Australian Winter Cereals Collection, Tamworth, NSW. These included Garry (Kochman and Brown, 1975), Andrew (Clifford, 1968), Brunker (Luke *et al.*, 1972), Lodi, Ajax and Portage (Heagle and Moore, 1970; Singleton *et al.* 1982) and Red Rustproof (Luke *et al.* 1981).

Field Screenings

All cultivars cited in the literature and obtained from Tamworth were included in the field trials of the International oat lines at the QWRI from 1989 to 1992. Artificial epidemics were created by inoculating spreader rows with race 264 in either April or May. Disease assessments were carried out several times during the year. These assessments were based on 1. reaction ie. resistant, moderately resistant, moderately susceptible, susceptible or very susceptible and 2. the percentage of leaf tissue rusted.

Those cultivars expressing moderate resistance to moderate susceptibility were noted and examined more closely in the glasshouse, initially to ascertain which of the resistance components could be used as an indicator of partial resistance (slow-rusting).

Development of glasshouse screening technique

The first series of experiments included the cultivars Ascencao, Panfive and Sual owing to their reactions in the field (Table 1). Garry was included in the experiments due to its slow-rusting nature when compared to the highly susceptible cultivar Algerian (Kochman and Brown 1975). In all glasshouse experiments, Algerian and Saia were used as the standard susceptible and resistant controls respectively. These initial studies investigated the components involved in the resistance response including latent period, infection efficiency, uredium density and size and spore production.

Growth of Plants and Inoculation Procedures

Seeds of each of the cultivars were pregerminated for 24 hours before being planted in U.C. mix (1:3 v:v peat:sand) in 12 cm-diameter pots. Three replicate pots, each containing six seeds were planted per cultivar for each leaf age treatment. Plants were inoculated when the first or primary leaf was fully expanded (8 - 9 days).

Plants were inoculated by lying the leaves flat on a piece of cardboard, abaxial side up and held in place by two rubber bands. The plants were placed in a spore settling tower (Brown and Kochman, 1973) and inoculated with 10 mg of uredospores of race 264 of Pca. The inoculum was fired into the tower using a modified air rifle and the baffle plate was removed after approximately five seconds. Plants were then left in the tower for six minutes for the spores to settle.

This gave a deposition of 540 uredospores per cm^2 with a coefficient of variation of 27%. Following inoculation, plants were incubated overnight (20 to 22 hrs) in a dew chamber at 21 ± 1°C after which they were transferred to a temperature controlled cabinet maintained at 23° ± 2°C and watered daily.

Results and Conclusions

Results concerning the development of the glasshouse screening technique were published in the Australian Journal of Agricultural Research **43:**1217-27 (1992) and presented as a paper at the 4th International Oat Conference, Adelaide, 1992.

In brief, this work indicated that uredium density (and infection efficiency) were the components which gave the best indication of partial resistance and that screening for this type of resistance could be carried out by inoculating the primary (or first) leaf of a seedling using a spore settling
tower (Brown and Kochman 1973).

Promising partially resistant cultivars or lines

Of the 14 cultivars screened in the glasshouse (Table 1) using the abovementioned technique, only three cultivars appeared to express partial resistance. In the glasshouse, Panfive expressed a lower uredium density and infection efficiency and produced fewer spores when compared to Algerian. As discussed in the paper, Panfive has consistently shown partial resistance to leaf rust both under experimental conditions and in the field (Irwin 1991). Consequently, Panfive appeared to be a cultivar expressing a level of partial resistance useful in the field. This cultivar was therefore included in all future experiments as a standard.

Andrew, a cultivar referred to as slow-rusting (Clifford 1968) and semi-tolerant (Simons 1966) appeared to be similar to Panfive in reaction ie. moderately susceptible to moderately resistant. In glasshouse experiments this cultivar appeared to express a very similar or slightly lower uredium density than Panfive and was always significantly more resistant than Algerian. In the field however, Andrew appeared susceptible to very susceptible (Table 1) exhibiting numerous large uredia and therefore did not appear to be of value to the program.

Another line which appeared to express moderate resistance is the Quaker line 51 (1986) (86QK 51). Although susceptible in the field, this line expressed small uredia with only 15 to 50% of the leaf tissue infected (Table 1). In the glasshouse, 86QK 51 expressed a somewhat lower level of resistance than that of Panfive but was significantly more resistant than Algerian (Table 2). 86QK 51 is also moderately resistant to the rust isolate capable of severely affecting Panfive which appeared in May-June 1992.

The remaining 30 cultivars screened in the field but not in the glasshouse were considered to be either too susceptible or too resistant for use as partially resistant cultivars. These included cultivars that were reported as being either slow-rusting or expressing moderate levels of disease resistance eg. Ajax, Portage, Brunker, Garry and Lodi.

Table 1. Rust ratings for oat lines, Toowoomba, 1989 and 1991

	Rating	% leaf infected	
Algerian	VS	80	
Ascencao	MR-MS	20	
Cypress	MS-S	30-50	
Garry	VS	90	
Mortlock	S	80	
Panfive	MR-MS	30-60	
Saia	R-MR	10	
Sual	S	70	
1983QK 113	MS-S	20-50	
1984QK 133	MR-MS	20-70	
1984QK 231 JO	R-MR	20-50	
1985QK 262	MS-MR	30	
1986IORN 117	R-MR	30-50	
MA5024	MR-MS	40-80	
Andrew	S	20	(June 1991)
	VS	60	(October 1991)
86QK-51	S	15	(June 1991)
	S	50	(October 1991)

R - Resistant; MR - Moderately Resistant; MS - Moderately Susceptible; S - Susceptible; VS - Very Susceptible

Table 2. Rust reactions and uredium densities for lines screened in experiment 11

	Reaction	Uredium Density (no./cm^2)
Algerian	S	25.28 a
MA5024	MS	20.95 ab
86QK-51	MR-MS	17.55 bc
Mortlock	MS-MR	12.37 c
Panfive	MR	6.13 d
85QK 262	HR	0.19 e

HR - Highly Resistant; MR - Moderately Resistant; MS - Moderately Susceptible; S - Susceptible
Within columns, means followed by the same letter are not significantly different ($P < 0.05$).

Breeding for partial resistance

Crosses were made between Panfive and Ascencao and Panfive and Pan 4 at the University of Queensland during 1990 in an attempt to develop cultivars with resistance similar to or better than Panfive. Ascencao contains at least one rust resistance *Pc* gene, *Pc* 14 and expresses moderate to high levels of resistance to many races of Pca. Pan 4, derived from 862C1217 x (2590-1 x 2638-1), was used in the crosses due to its Algerian like habit ie. prostrate and narrow leaved.

F_2 seeds of one Panfive x Pan 4 and three Panfive x Ascencao crosses were grown in the field at Toowoomba to screen for resistance to Pca. Single head selections of resistant to moderately resistant plants were made from the F_2, F_3 and F_4 generations of each of the crosses. Four resistant Pan 4 x Panfive and five resistant Panfive x Ascencao lines were selected from the plants grown at Toowoomba and the F_5 seed of these lines is now in the possession of Pacific Seeds Pty. Ltd. who will be commercialising the best of these lines following further testing. In addition, F_3 seed of the Pan 4 x Panfive cross was grown and screened in the glasshouse from which 17 lines were selected for their resistance. The F_4 seed of these lines will be passed onto Pacific Seeds Pty. Ltd for further testing and possible commercialisation.

In May-June 1992, an outbreak of leaf rust was found on Panfive growing near Toowoomba. This race, identified as race 276 (45, 48), was able to overcome the partial resistance of Panfive and as a result, Panfive will now have limited use. However as previously mentioned, Panfive has been crossed with both Ascencao and Pan 4. Ascencao expresses moderate resistance to many races including race 276 (45, 48) which infects Panfive and as pointed out above, several resistant lines from the Panfive x Ascencao cross have been identified and taken up by Pacific Seeds Pty. Ltd. Similar attempts to develop resistant cultivars will also be made with 86QK-51 which also exhibits resistance to race 276 (45, 48).

While difficulties do exist in attempting to identify partially resistant cultivars, particularly ones which are non-race specific and perhaps more durable, the research carried out over the past three years has provided a foundation for continuing work. The glasshouse screening technique has enabled the identification of partially resistant cultivars which can be used in future breeding programs.

PART 3 DETAILED REPORT

1. Screening for Partially Resistant Cultivars

(i) Background

In subtropical Australia, oats are grown as a major winter forage crop with approximately 300 000 ha of oats grown in Queensland in 1988. Compared to wheat and barley, oats have a greater ability to regenerate after grazing and are therefore preferred. However, oats are susceptible to a number of rust diseases. In subtropical Australia, leaf or crown rust caused by *Puccinia coronata* f. sp. *avenae* (Pca) is one of the major diseases affecting oats. When oats are planted early in the season (February, March, April), build up of inoculum occurs early on. This inoculum is then present for a long period of time (May to October) during which conditions ideal for rust epidemics occur. The grazing potential of an oat crop may be reduced by up to 50% as a result of an epidemic as was the case in 1988 when much of southeast Queensland experienced a mild wet winter.

Although cultivars resistant to Pca are available, races of the pathogen capable of infecting these cultivars have appeared relatively quickly (ie. within 5 years). The nature of resistance in these cultivars has generally been complete ie. allowing little or no rust development. However, cultivars expressing slow-rusting (partial or incomplete resistance) may express a more durable resistance in the field due, in part, to the reduction in the selection pressure on the pathogen.

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The common occurrence of oat leaf rust epidemics in Queensland has prompted the search for partially resistant oat cultivars. The aim of this research was therefore -

1. To select and release rust-resistant oats cultivars prior to identification of slow-rusting characteristics and release of slow-rusting cultivars.
2. To screen oat cultivars in the glasshouse for slow-rusting characteristics.
3. To investigate the effectiveness of slow-rusting cultivars of oats in controlling crown rust in the field.
4. To investigate the mechanisms (eg. incubation period, number of pustules produced, etc.) which contribute to slow-rusting.

(iii) Methods

<u>Sources of partially resistant cultivars or lines</u>

Candidate lines or cultivars for this project were sought through both field screenings and the literature. Field screenings of International oat lines conducted at the Queensland Wheat Research Institute (QWRI) Toowoomba, Qld, provided a source of slow-rusting material. This field screening site at the QWRI also provided a means by which any promising material could be screened in the field over a number of years while at the same time being investigated in the glasshouse.

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Those cultivars expressing moderate resistance to moderate susceptibility were noted and examined more closely in the glasshouse, initially to ascertain which of the resistance components could be used as an indicator of slow-rusting.

Development of glasshouse screening technique

The first series of experiments included the cultivars Ascencao, Cypress, 1986IORN 117, Panfive and Sual owing to their reactions in the field (Table 1.1). Garry was included in the experiments due to its slow-rusting nature when compared to the highly susceptible cultivar Algerian (Kochman and Brown 1975). In all glasshouse experiments, Algerian and Saia were used as the standard susceptible and resistant controls respectively. These initial studies investigated the components involved in the resistance response including latent period, infection efficiency, uredium density and size and spore production.

Growth of Plants and Inoculation Procedures

Seeds of each of the cultivars were pregerminated for 24 hours before being planted in U.C. mix (1:3 v:v peat:sand) in 12 cm diameter pots. Three replicate pots, each containing six seeds were planted per cultivar for each leaf age treatment. Seeds were oriented in the one direction in the pots to facilitate inoculation of the leaves. Plants were inoculated when the first (or primary) leaf was fully expanded (8 - 9 days old). Plants were inoculated by lying the leaves flat on a piece of cardboard, abaxial side up and held in place by two rubber bands. The plants were placed in a spore settling tower (Brown and Kochman, 1973) and inoculated with 10 mg of uredospores of race 264 of Pca. The inoculum was fired into the tower using a modified air rifle and the baffle plate was removed after approximately five seconds. Plants were then left in the tower for six minutes for the spores to settle. This gave a deposition of 540 uredospores per cm^2 with a coefficient of variation of 27%. Following inoculation, plants were incubated overnight (20 to 22 hrs) in a dew chamber at 21 ± 1°C and then transferred to a temperature controlled cabinet maintained at 23° ± 2°C and watered daily.

Table 1.1 Rust ratings for oat lines, Toowoomba, 1989

	Rating	% leaf infected
*Algerian	VS	80
*Ascencao	MR-MS	20
*Cypress	MS-S	30-50
*Garry	VS	90
*Mortlock	S	80
*Panfive	MR-MS	30-60
*Saia	R-MR	10
*Sual	S	70
Q19018	R-MR	35-50
*1983QK 113	MS-S	20-50
1983QK 200	R	10-20
1983QK 300	R	15-20
*1984QK 133	MR-MS	20-70
1984QK 162	R	5-30
1984QK 188	MR-MS	25-60
*1984QK 231 JO	R-MR	20-50
1984QK 243	R	15-30
1985QK 216	R	20-40
*1985QK 262	MS-MR	30
1986IORN 114	MR	35-50
*1986IORN 117	R-MR	30-50
1986IORN 158	R	30-50
*MA5024	MR-MS	40-80

* Cultivars/lines tested using glasshouse screening technique

Table 1.2 Rust ratings of oat lines, Toowoomba and Gatton, 1990

	Toowoomba		Gatton	
	Rating	**% leaf infected**	**Rating**	**% leaf infected**
Ajax	MS-S	30	VS	30
Algerian	MS-S	20	VS	90
Ascencao	MR-MS	15	S	5
Brunker	MS-S	20	VS	60
Cypress	MR-R	5	S	20
Garry	MS-S	25	S	5
Lodi	MS-S	25	VS	10
Mortlock	MS-S	20	S	60
Panfive	MR	5	VS	5
Portage	MS	15	VS	20
Saia	R	0	MR	15
Sual	MS-S	13	S	5
MA5024	MR-R	10	S	40

Table 1.3 Rust ratings for oat lines grown at Toowoomba, 1991

	June		October	
	Rating	**% leaf infected**	**Rating**	**% leaf infected**
Red rustproof	S	25	VS	50
*Andrew	S	20	VS	60
Q86-37	S	25	S	35
*Q86-51	S	15	S	50
Q87-81	VS	15	VS	65
Q87-103	S	15	VS	40
Q87-107	S	10	R	5
Q88-175	R	2	MS	20
Q88-188	R	2	S	35
Q88-189	MS	5	S	25
Algerian	S	20	S	8
Q88-190	MR-MS	5	S	20
Q88-191	R	0	S	20
Q88-196	S	40	MS	15
Q88-201	S	75	MS	10
Q88-204	MS-S	40	S	35
Q88-206	S	80	S	30
34-A1-11-1-2	MS-S	30-90	S	30
CI7073	S	35-95	VS	60
85QK216	MS-S	45	R	5
Mortlock *	S	20-75	S	30
Panfive *	MS	5	S	20

* Cultivars/lines tested using glasshouse screening technique

Table 1.4 Rust reactions and uredium densities for lines screened in experiment 7

	Reaction	Uredium Density (no./cm^2)
Algerian	S	38.00 a
Andrew	MS	25.28 b
Panfive	S	32.39 c
83 QK 113	NI	0.99 d
Saia	HR	0.68 d

NI - Nearly Immune; HR - Highly Resistant;
MR - Moderately Resistant; MS - Moderately Susceptible;
S - Susceptible
Within columns, means followed by the same letter are not significantly different ($P < 0.05$).

Table 1.5 Rust reactions and uredium densities for lines screened in experiment 9

	Reaction	Uredium Density (no./cm^2)
Algerian	MS	19.24 a
MA5024	MS	14.76 b
Andrew	MS	13.26 b
Panfive	MR-MS	11.56 b
84 QK 133	NI	0.11 c
84 QK 231	NI	0.04 c

NI - Nearly Immune; HR - Highly Resistant;
MR - Moderately Resistant; MS - Moderately Susceptible;
S - Susceptible
Within columns, means followed by the same letter are not significantly different ($P < 0.05$).

Table 1.6 Rust reactions and uredium densities for lines screened in experiment 11

	Reaction	**Uredium Density (no./cm^2)**
Algerian	S	25.28 a
MA5024	MS	20.95 ab
86QK-51	MR-MS	17.55 bc
Mortlock	MS-MR	12.37 c
Panfive	MR	6.13 d
85QK 262	HR	0.19 e

HR - Highly Resistant; MR - Moderately Resistant;
MS - Moderately Susceptible; S - Susceptible
Within columns, means followed by the same letter are not significantly different ($P < 0.05$).

(iv) Results

Results of this work were published in the Australian Journal of Agricultural Research **43:**1217-27 (1992) and presented as a paper at the 4th International Oat Conference, Adelaide, 1992.

In brief, this work indicated that uredium density (and infection efficiency) were the components which gave the best indication of partial resistance and that screening for this type of resistance could be carried out by inoculating the primary (or first) leaf of a seedling using a spore settling tower (Brown and Kochman 1973). It should be noted that cv. Cypress and the line IORN 117 do not appear in the published work as they were highly resistant and of no further interest.

<u>Promising partially resistant cultivars or lines</u>

Of the 14 cultivars screened in the glasshouse (Tables 1.1, 1.2, 1.3) using the abovementioned technique, only three cultivars appeared to express partial resistance. In the glasshouse, Panfive expressed a lower uredium density and infection efficiency and produced fewer spores when compared to Algerian (refer to paper). As discussed in the paper, Panfive has consistently shown partial resistance to leaf rust both under experimental conditions and in the field (Irwin 1991). Consequently, Panfive appeared to be a cultivar expressing a level of partial resistance useful in the field. This cultivar was therefore included in all future experiments as a standard.

Andrew, a cultivar referred to as slow-rusting (Clifford 1968) and semi-tolerant (Simons 1966) appeared to be similar to Panfive in reaction ie. moderately susceptible to moderately resistant. In glasshouse experiments this cultivar appeared to express a very similar or slightly lower uredium density than Panfive and was always significantly more resistant than Algerian (Tables 1.4, 1.5). In the field however, Andrew appeared susceptible to very susceptible (Table 1.3) exhibiting numerous large uredia and therefore did not appear to be of value to the program.

Another line which appeared to express moderate resistance resistance is the Quaker line 51 (1986) (86QK 51). Although susceptible in the field, this line expressed small uredia with only 15 to 50% of the leaf tissue infected (Table 1.3). In the glasshouse, 86QK 51 expressed a somewhat lower level of resistance than that of Panfive but was significantly more resistant than Algerian (Table 1.6). 86QK 51 is also moderately resistant to the rust isolate capable of severely affecting Panfive which appeared in May-June 1992.

The remaining 30 cultivars screened in the field but not in the glasshouse were considered to be either too susceptible or too resistant for use as partially resistant cultivars. These included cultivars that were reported as being either slow-rusting or expressing moderate levels of disease resistance eg. Ajax, Portage, Brunker, Garry and Lodi.

2. Inheritance of Partial Resistance of Panfive

(i) Background

While partially resistant or slow-rusting oat cultivars have been identified, they are very few in number. This may be due, in part, to the lack of interest in this area in the past and perhaps the lack of obvious material exhibiting the desired characteristics. As previously mentioned, a number of partially resistant or slow-rusting oat cultivars have been mentioned in the literature and several possible lines were obtained from the field trials at Toowoomba. However, many of the cultivars cited in the American literature were of no value in the Australian environment. Attempts were therefore made to develop cultivars with resistance similar to or better than that of Panfive by crossing Panfive with both Ascencao and Pan 4. Ascencao contains at least one rust resistance *Pc* gene, *Pc* 14 and expresses moderate to high levels of resistance to many races of Pca. Pan 4, like Panfive, was selected from crosses made between Lodi and P.I. 267989 (*A. sterilis*) (Irwin 1991).

(ii) Methods

Crosses were made between Panfive and Ascencao and Panfive and Pan 4 at the University of Queensland during 1990.

F_2 seeds of one Panfive x Pan 4 and three Panfive x Ascencao crosses were grown in the field at the Wheat Research Institute, Toowoomba to screen for resistance to Pca. F_2 seeds from these crosses were also used for glasshouse experiments to determine the heritability of resistance in Panfive.

<u>Plant Material</u>

Seeds of the F_2 populations of the crosses and all parents (Ascencao, Panfive and Pan 4) were pregerminated overnight on moist filter paper. Five seeds per pot were planted and grown under natural light conditions in a temperature controlled cabinet maintained at 23 $\pm$ 2°C. At 15 days of age with the second leaf fully expanded all plants were inoculated.

<u>Inoculation Method</u>

Inoculation was carried out in a settling tower as described in the paper (AJAR) using 10 mg uredospores of race 264 of Pca per run in the tower. The inoculated seedlings were incubated overnight in a darkened dew chamber maintained at 21 $\pm$ 2°C. The plants were then transferred to a temperature controlled growth cabinet maintained at 23 $\pm$ 2°C.

Disease Assessment

Nine days after inoculation, the reaction of each plant was assessed and leaves were harvested by cutting at the axil and preserving in water to which had been added 3 to 4 ml of aniline blue. Uredium density (number/cm^2) was determined by counting all uredia greater than 0.4 mm in length and dividing by the leaf area which was obtained using a planimeter (Delta-T Devices). The length and breadth of 20 randomly selected uredia were measured. The formula for an ellipse, 1/4 (length x breadth) was then used to determine the areas of the uredia (mm^2).

Statistical Analysis

Data for uredium density and size was subjected to Chi-square analysis to test for agreement between the observed and expected ratios, based on various models (Zar 1984).

In the analyses, Ajax is assumed to lack resistance genes to any races of Pca prevalent in Australia.

(iii) Results

Panfive x Ajax

Uredium density

Uredium densities for Panfive ranged from 20 to 56 uredia/cm^2 (Fig. 2.1 a). Larger uredium densities were expressed by Ajax which also exhibited a broader range of densities extending from 32 to 124 uredia/cm^2 (Fig. 2.1 b). Uredium densities for the F_2 progeny of the Panfive x Ajax cross ranged from as few as 24 to as many as 124 uredia/cm^2 (Fig. 2.1 c).

For statistical analysis, the demarcation point between partially resistant and susceptible plants was set at 56 uredia/cm^2. This gave a ratio of 9 resistant: 24 susceptible for the F_2 progeny. When subjected to a chi-square analysis the observed ratio gave a good fit to the expected ratio of 1:3 resistant:susceptible (P = 0.76) (Table 2.1).

Table 2.1 Chi-square analysis of goodness of fit to 3 susceptible to 1 resistant segregation for an F_2 population from the cross Panfive x Ajax based on uredium density.

Cultivar	No. Plants Resis	Susc	Expected Resis	Susc	X^2	P
Panfive	14	1	15	0	-	-
Ajax	2	18	0	20	-	-
Panfive x Ajax (F_2)	9	24	8.25	24.75	0.091	0.76

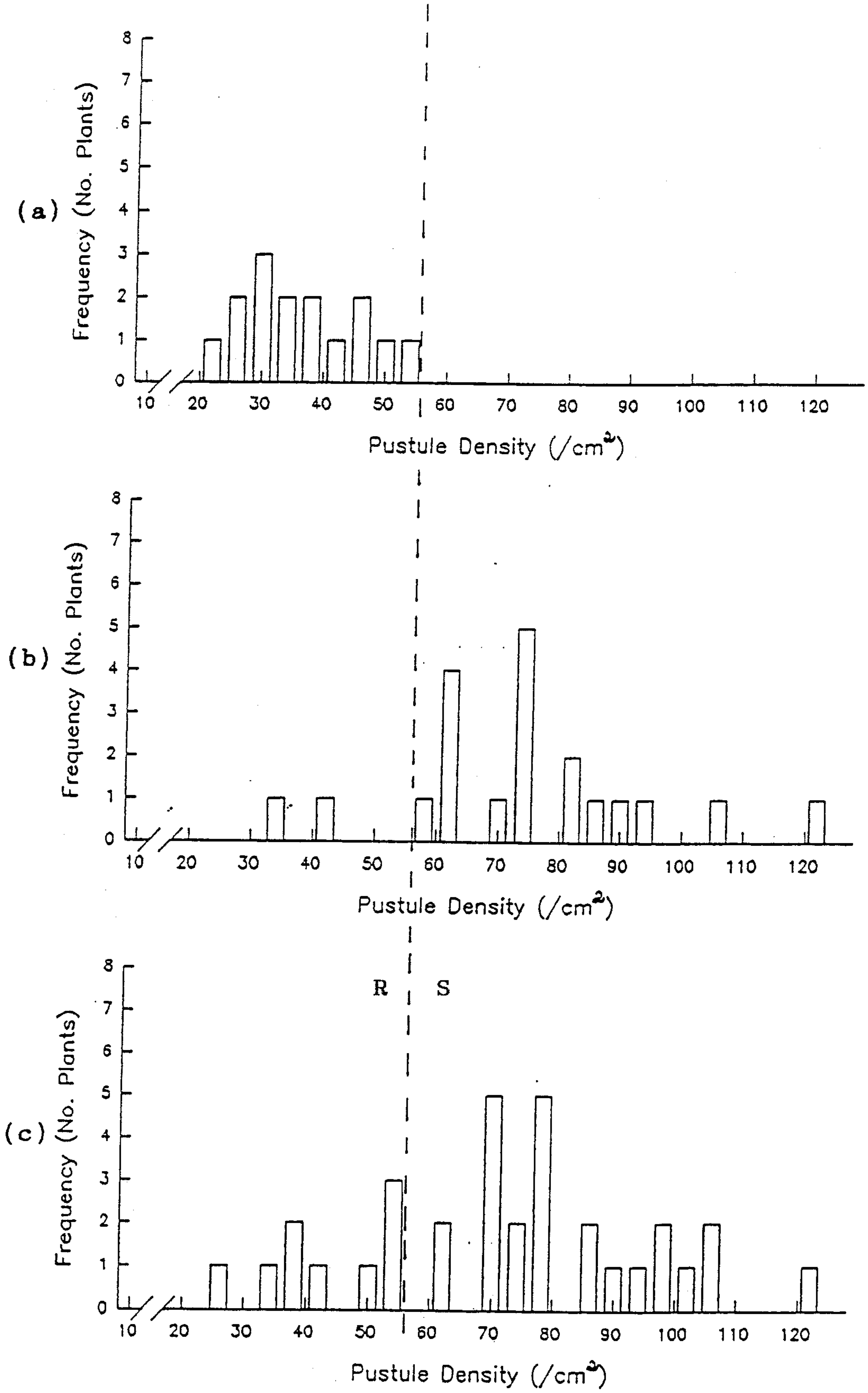

FIGURE 2.1 Histograms of the frequency of plants with various uredium densities for the parents, Panfive (a), Ajax (b) and the F_2 population (c) when infected with Pca race 264.

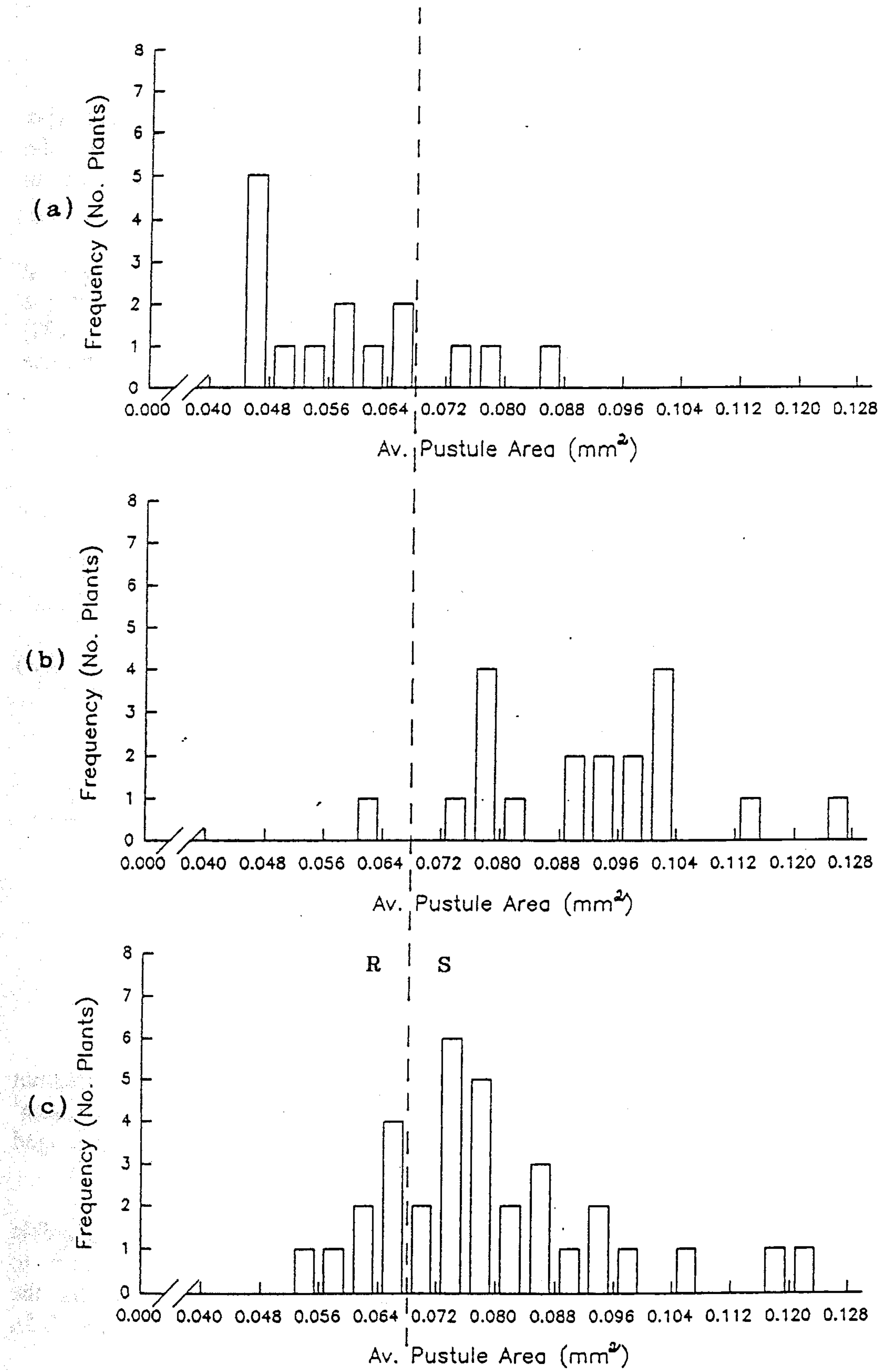

FIGURE 2.2 Histograms of the frequency of plants with various uredium size for the parents, Panfive (a), Ajax (b) and the F_2 population (c) when infected with Pca race 264.

Uredium Size

Uredium size for Panfive ranged from 0.044 mm^2 to 0.088 mm^2, while for Ajax they ranged from 0.060 to 0.128 mm^2. Uredium size for the F_2 progeny of the Panfive x Ajax cross, expressed a similar range to those on Ajax ranging from 0.052 to 0.124 mm^2 (Figs. 2.2 a, b, c).

The demarcation point between resistant and susceptible plants was set at 0.068 mm^2 resulting in an observed ratio of 8 resistant to 25 susceptible for the F_2 population. When subject to a chi-square analysis, this ratio gave a good fit (P = 0.92) to the 1:3 resistant:susceptible ratio, again indicating the recessive nature of the resistance (Table 2.2).

Table 2.2 Chi-square analysis of goodness of fit to 3 susceptible to 1 resistant segregation for an F_2 population from the cross Panfive x Ajax based on uredium size.

Cultivar	No. Plants		Expected		X^2	P
	Resis	Susc	Resis	Susc		
Panfive	12	3	15	0	-	-
Ajax	1	19	0	20	-	-
Panfive x Ajax (F_2)	8	25	8.25	24.75	0.01	0.92

Panfive x Ascencao

Uredium Density

Uredium densities for Panfive ranged from 12 to 46 uredia/cm^2 while the uredium density for Ascencao was lower with a narrower range extending from 0 to 4 uredia/cm^2 (Fig. 2.3). Uredium density for the F_2 population of the Panfive x Ascencao cross ranged from as few as 0 to 40 uredia/cm^2 (Fig. 2.3).

For statistical analysis, the demarcation point between resistant and susceptible plants was set at 10 uredia/cm^2 which gave an observed ratio of 43 resistant to 11 susceptible for the F_2 population. Chi-square analysis of this data showed that the observed ratio did fit an expected 3:1 resistant:susceptible ratio (P = 0.43) (Table 2.3), indicating the resistance in Ascencao is conditioned by a single dominant gene.

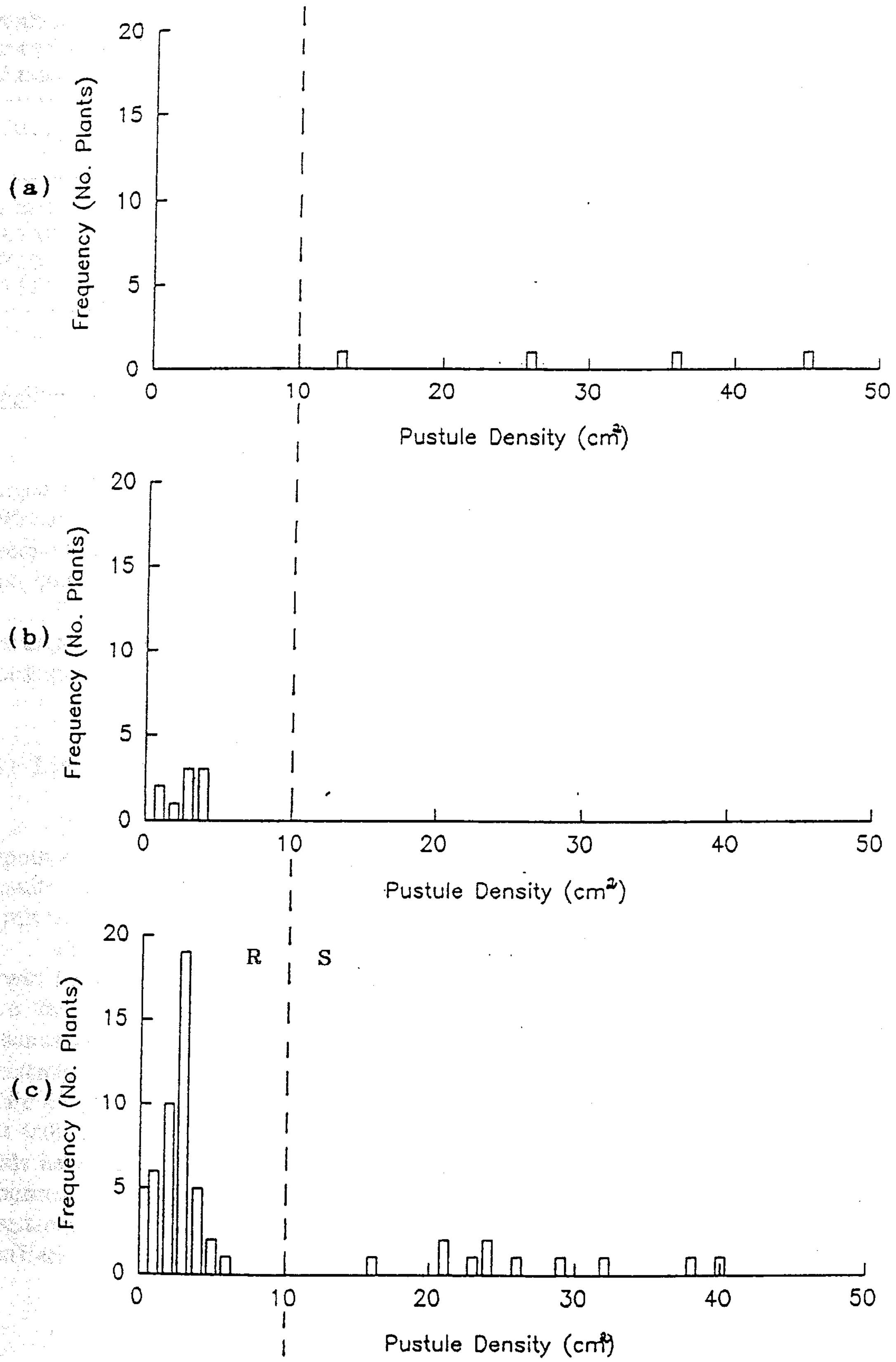

FIGURE 2.3 Histograms of the frequency of plants with various uredium densities for the parents, Panfive (a), Ascencao (b) and the F_2 population (c) when infected with Pca race 264.

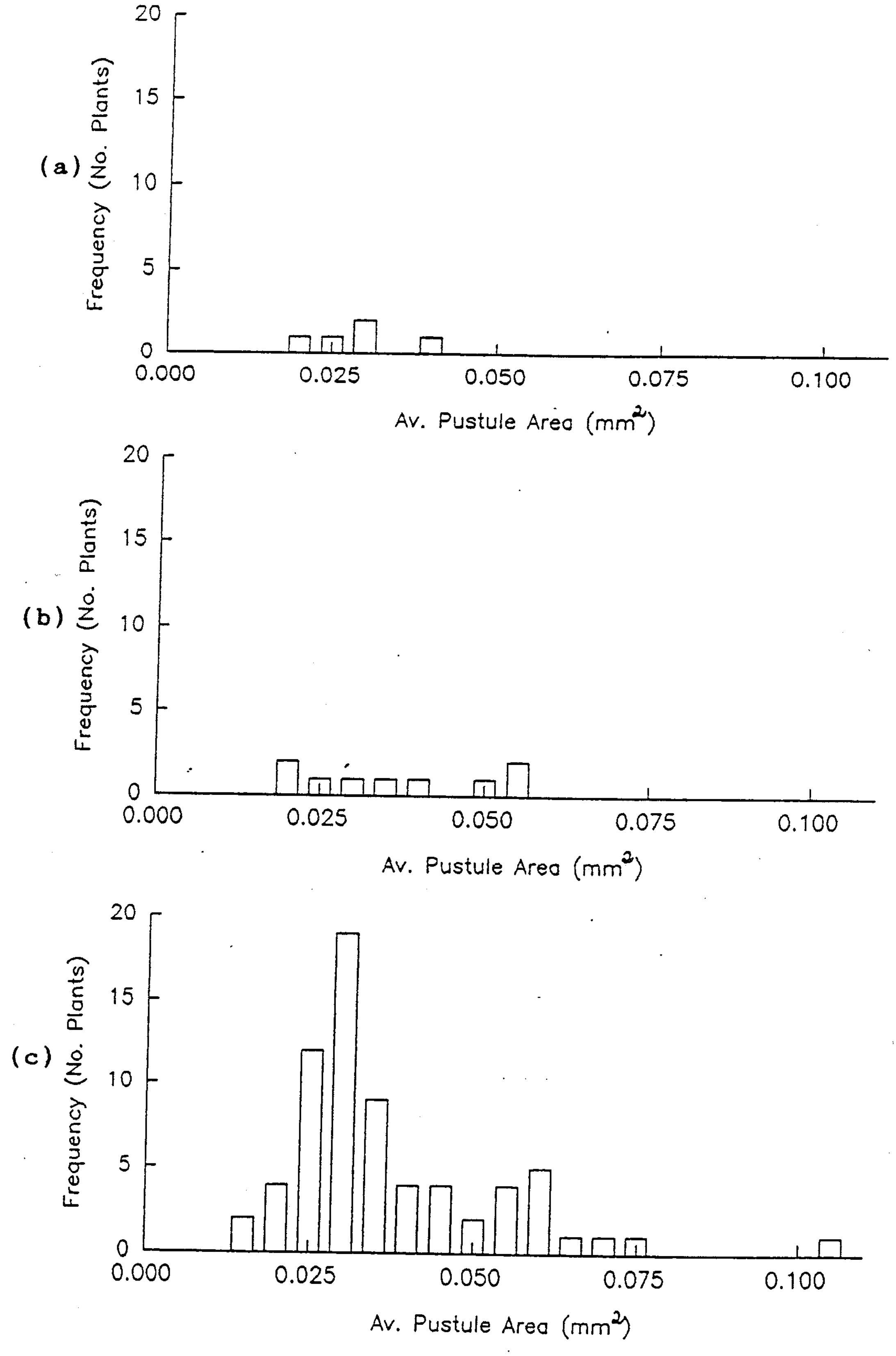

FIGURE 2.4 Histograms of the frequency of plants with various uredium size for the parents, Panfive (a), Ascencao (b) and the F_2 population (c) when infected with Pca race 264.

Table 2.3 Chi-square analysis of goodness of fit to 3 resistant to 1 susceptible segregation for an F_2 population from the cross Panfive x Ascencao based on uredium density.

Cultivar	No. Plants		Expected		X^2	P
	Resis	Susc	Resis	Susc		
Panfive	0	9	0	9	-	-
Ajax	4	0	4	0	-	-
Panfive x Ajax (F_2)	43	11	40.5	13.5	0.617	0.43

Uredium Size

Uredia size for Panfive ranged from 0.02 to 0.04 mm^2, while for Ascencao uredia ranged from 0.02 to 0.06 mm^2 showing a great overlap in uredium size for the parental cultivars (Figs. 2.4 a,b).
Uredium size for the F_2 progeny of the Panfive x Ascencao cross, expressed a wider range than both of the parents, ranging from 0.015 to 0.105 mm^2 (Fig. 2.4 c).

Due to the overlap between parental cultivars with respect to size data, a demarcation between resistant and susceptible types could not easily be made. Consequently a chi-square analysis was not carried out on this data.

(iv) Discussion

Results of the analyses on data for both uredium density and size supports the hypothesis that the partial resistance of Panfive is conditioned by a single recessive gene. Results based on uredium density also supported the hypothesis that a single completely dominant gene conditions the resistance of Ascencao.

Panfive was selected from the progeny of a cross between Lodi and P.I. 267989 (Irwin 1991). Lodi is susceptible in the seedling stage to a number of Pca races including race 264, but has been shown to exhibit a degree of adult plant resistance to this race (Shands and Forsberg 1966). The cultivar P.I. 267989 possesses a dominant gene for resistance to Pca race 264. This gene was designated *Pc* 36 and is believed to be identical to *Pc* 47 (Fleischmann *et al.*, 1971, Simons *et al.*, 1978). The results of the experiment do not indicate that Panfive has received the *Pc* 36 gene as both glasshouse tests and field trials have shown that Panfive exhibits partial resistance to race 264. Panfive may have inherited resistance genes conditioning the adult plant resistance in Lodi. However, other resistance genes which are, as yet unidentified in the parents, may have also been transferred.

Although reported as being slow-rusting (Heagle and Moore 1970), field trials and glasshouse tests in Queensland have shown Ajax to be highly susceptible to Pca races prevalent in Australia. Ajax therefore appears to contain very few, if any resistance genes effective against Australian races of Pca. Thus it is assumed that any resistance expressed by the F_2 progeny was due to resistance inherited from Panfive. Owing to the distribution of uredium densities and sizes in the F_2 progeny of the Panfive x Ajax cross, the resistance of Panfive appears to be conditioned by a single recessive gene.

The cultivar Ascencao reportedly possesses the dominant *Pc* 14 gene for resistance to several races of Pca (Simons 1956). The inheritance studies reported here, indicate that resistance in the F_2 progeny of the Panfive x Ascencao crosses was conditioned by a single dominant gene. The high level of resistance expressed by *Pc* 14 appears to mask the partial resistance of Panfive. The more resistant plants of the F_2 population were so highly resistant it is not known if there was an additive effect of the different resistance genes.

Field screenings of F_2, F_3 and F_4 populations of the Pan 4 x Panfive and Panfive x Ascencao crosses.

Single head selections of resistant to moderately resistant plants grown in the field at Toowoomba, were made from the F_2, F_3 and F_4 generations of each of the crosses. Four resistant Pan 4 x Panfive and five resistant Panfive x Ascencao lines were selected from the plants grown at Toowoomba and the F_5 seed of these lines is now in the possession of Pacific Seeds who will be commercialising these lines following further testing. In addition, F_3 seed of the Pan 4 x Panfive cross was grown and screened in the glasshouse from which 17 lines were selected for their resistance. The F_4 seed of these lines will be passed onto Pacific Seeds Pty. Ltd. for further testing and possible commercialisation.

3 Specificity of Partial Resistance in Panfive

(i) Background

Partial resistance is a form of resistance in which the pathogens rate of colonisation and reproduction are reduced, although the plants are regarded as being susceptible. Partial resistance (slow-rusting) is generally thought to be effective against most, if not all races of a pathogen and as such is sometimes referred to as horizontal resistance. Partial resistance may however, be specific to certain races (Johnson 1984). To be of value in the field, partial resistance needs to be effective against all races of the pathogen. The resistance of Panfive was therefore tested against three races of Pca to determine whether specificity was present in this host-pathogen interaction.

(ii) Methods

Plant Material

Seeds of both Panfive and Algerian were pregerminated overnight on watersoaked filter paper in petri dishes. Five seeds were planted per pot using U.C. mix. Fifteen pots of each of the two cultivars were allowed to grow in a temperature controlled cabinet maintained at 23 $\pm$ 2°C under natural light conditions. Plants were inoculated when the primary leaf was fully expanded.

Inoculation Method

Inoculations were carried out in the settling tower using 10 mg of uredospores of races 216, 264 and 276 of Pca. All equipment and benches were thoroughly swabbed with 95% alcohol between inoculations with the different races. After inoculation, the plants were incubated overnight in a darkened dew chamber at 21 $\pm$ 2°C before being transferred to a temperature controlled cabinet maintained at 23 $\pm$ 2°C.

Disease Assessment

Eleven days after inoculation, plants were assessed for reaction type and the leaves harvested as described previously. Uredium density (no./cm^2) was determined by counting all uredia greater than 0.4 mm in length and dividing by the leaf area which was obtained using a planimeter. The lengths and breadths of 20 randomly selected uredia were measured and the size (mm^2) obtained using the formula of an ellipse, 1/4 (length x breadth).

Methods of statistical analysis

Data for uredium density and size were subjected to a one way analysis of variance using the SAS computer program (1987). Tests between means were carried out using the t-test (Zar (1984).

(iii) Results

Panfive was moderately resistant to race 216 but was moderately susceptible to races 264 and 276. Algerian was moderately susceptible to susceptible to all three races.

Uredium Density

Uredium density (no./cm^2) for cv. Algerian differed to that of Panfive in that race 276 produced the lowest density of all the races on Algerian whereas it produced the highest density on Panfive. Significant differences between races were only present for Panfive, where each race produced significantly different densities to one another (Table 3.1).

Uredium Size

While uredium size (mm^2) was generally smaller for cv. Panfive than Algerian for all three races, both cultivars responded in the same manner ie. race 264 produced the smallest uredia while race 276 produced the largest uredia. However, for Panfive, race 276 produced significantly larger uredia than races 264 and 216 (Table 3.2).

Table 3.1 Mean uredium density for cultivars Algerian and Panfive.

Race	Algerian	Panfive
264	31.96 a	13.32 a
216	26.94 a	5.06 b
276	21.33 a	17.82 c

Within columns, figures followed by the same letter are not significantly different (P = 0.05).

Table 3.2 Mean uredium size for cultivars Algerian and Panfive.

Race	Algerian	Panfive
264	0.190 a	0.137 a
216	0.207 a	0.141 a
276	0.224 a	0.234 b

Within columns, figures followed by the same letter are not significantly different (P = 0.05).

(iv) Discussion

Compared to Algerian, Panfive expressed greater resistance to all three races tested, in particular to 216. This was evident from both the density and size data. While there were differences between the races on Panfive particularly with respect to uredium density, Panfive always appeared more resistant than Algerian. The resistance of Panfive to the three races tends to indicate that the resistance component of Panfive may be largely race non-specific.

Studies on *Puccinia graminis* f. sp. *avenae*/*Avena sterilis* and the *P. graminis* f. sp. *tritici*/*Triticum aestivum* interactions have revealed no specificity of the partial resistance characteristic (Sztejnberg and Wahl 1976, Wahl *et. al.* 1980). Similar race non-specificity has been reported for wheat infected with *P. reconditia* f. sp. *tritici* (Kuhn, Ohm and Shaner 1978). Luke *et al.* (1975) have reported that Red Rustproof 14 (*A. byzantina*) is slow-rusting and that the horizontal resistance expressed by this oat cultivar is not influenced by changes in rust races, having remained stable for more than 20 years.

This form of resistance, if it can be identified, presents a very attractive alternative to complete resistance. However, as pointed out by Johnson (1984), stable or durable resistance, can only be identified in hindsight. While a cultivar may appear to express resistance, whether complete or partial, to a number of races of a pathogen, it is only with time that we will be able to say with any certainty that the resistance was durable.

Panfive has been grown both in the field both under commercial and experimental conditions since 1985 and 1981 respectively (Irwin 1991). However, it has not been grown over a wide geographical region and as such has not been exposed extensively to the pathogen. How it will perform given different environmental conditions and races of the pathogen is not known although new evidence has indicated that the partial resistance of Panfive does appear to possess some degree of race specificity.

4 Race Identification of an Isolate of *Puccinia coronata* f. sp. *avenae* Infecting Panfive

(i) Background

Where breeding programs to incorporate resistance are in operation, a need arises to follow the virulence dynamics of the pathogen. This is achieved by conducting annual race surveys and assessing the response of each isolate on a set of differential cultivars, as occurs with leaf rust (Oates 1989). The resistant and susceptible reactions on given host cultivars will distinguish which race is present relative to other previous races.

In May-June 1992, a race of Pca appeared which severely affected the cultivar Panfive. This investigation attempts to identify the race of the pathogen responsible for the epidemic.

(ii) Methods

Plant material

A set of 28 oat cultivars, including 10 international differentials and 18 additional local cultivars, were used in the experiment. Five seeds of each cultivar were planted in 8 cm pots using U.C. mix (1:3 v:v peat:sand), with two replicate pots per cultivar.

Seedlings were watered daily and grown under glasshouse conditions at 25 $\pm$ 2°C for 14 and 28 days before being inoculated.

Inoculation Method

Isolates of *P. coronata* f. sp. *avenae* used in the experiment included race 264 and the isolate capable of infecting Panfive (UQ5). This new isolate was single pustuled and increased on the highly susceptible cultivar Swan. Spores were collected using a vacuum pump and then dried overnight over 60% sulphuric acid.

One replicate pot from each cultivar was inoculated using each race. The youngest fully expanded leaf was inoculated by attaching the leaf to cardboard with the underside up. After moistening the leaf surfaces, plants were then placed within a spore settling tower for inoculation. Approximately 0.005 g of uredospores was then fired into the settling tower and left to settle on the plants for six minutes. The tower was swabbed with 70% alcohol between each inoculation to avoid cross contamination.

Inoculated plants were incubated overnight in a darkened dew chamber maintained at 21 $\pm$ 2°C and then transferred to a 24°/20° C day/night glasshouse subject to natural light conditions.

Disease Assessment

After 10 days, the reaction of each cultivar was assessed. Seedlings were classed as either susceptible or resistant according to the standard rust rating scale (Simons 1970).

Disease reactions for the differential set exposed to the UQ5 isolate were then used to determine which race was responsible for the epidemic.

The whole experimental procedure was conducted on two separate occasions under almost identical experimental conditions with assessments made on 14/8/92 using plants inoculated at 28 days of age, and on 22.210/92 using plants inoculated at 14 days of age.

(iii) Results

Race 264 was correctly identified on both occasions according to the response of the international differentials (Simons and Murphy 1958), with all cultivars except Saia being susceptible (Table 4.1). The additional lines Algerian, ANZ-1, Mortlock, Swan, *Pc* 45, Minhafer, 86QK 51 and Pan 4 were also susceptible (Table 4.2). Mortlock and Pan 4 differed in responses between experiments.

All international differentials except Saia and Victoria were susceptible to the UQ5 isolate which was then identified as race 276 (Oates 1989)(Table 4.1). In addition, Algerian, ANZ-1, ANZ-2, Mortlock, Pan 4, Panfive, Swan, *Pc* 45 and 48 and Minhafer were susceptible (Table 4.2). No discrepancies existed between the two experiments.

For comparison, the virulence pattern of isolate S3054 which was found on cv. Amby in 1991 are included. This isolate was also identified as race 276 based on the reactions of the international differential cultivars, but as can be seen from Table 4.2, the virulence pattern on the additional differential cultivars differs to that of the UQ5 isolate infecting Panfive.

Table 4.1 Reactions of the international oat differentials when infected with race 264 and UQ5

	14/8/92		22/10/92		
Cultivar	**264**	**UQ5**	**264**	**UQ5**	**S3054**
Anthony	S	S	S	S	S
Victoria	S	R	S	R	R
Appler	S	S	S	S	S
Bond	S	S	S	S	S
Landhafer	S	S	S	S	S
Santa Fe	S	S	S	S	S
Ukraine	S	S	S	S	S
Trispernia	S	S	S	S	S
Bondvic	S	S	S	S	S
Saia	R	R	R	R	R

S - Susceptible
R - Resistant

Table 4.2 Reactions of additional oat differentials when infected with races 264 and UQ5

	14/8/92		22/10/92		
Cultivar	**264**	**UQ5**	**264**	**UQ5**	**S3054**
Algerian	S	S	S	S	na
Ascencao	R	R	R	R	S
ANZ-1	S	S	S	S	S
ANZ-2	R	S	na	na	S
Mortlock	S	S	R	S	S
Pan 4	S	S	S	S	na
Panfive	R	S	R	S	na
Swan	S	S	S	S	S
Pc 38	R	R	R	R	R
Pc 39	R	R	R	R	S
Pc 45	S	S	S	S	S
Pc 48	R	S	R	S	S
Pc 50	R	R	R	R	R
Pc 55	R	R	R	R	R
Pc 56	R	R	R	R	R
Pc 58	R	R	R	R	S
Pc 59	R	R	R	R	S
86QK 51	na	na	S	R	na
Amby	na	na	R	R	S
Minhafer	na	na	S	S	na

S - Susceptible
R - Resistant
na - not inoculated/ did not germinate

(iv) Discussion

Results indicate that the isolate overcoming the partial resistance of Panfive is race 276. This race has been present in Australia for a number of years and was recently discovered on cv. Amby. However, race 276 infecting Amby does not have the same virulence pattern on the additional differential cultivars as the Panfive race 276. To avoid confusion, these two races will be identified as race 276 (45, 48) which infects Panfive and 276 (39, 45, 48, 58, 59) which infects Amby. Since the race infecting Amby has the same virulences as that of the race infecting Panfive, it would appear that the race infecting Panfive is the progenitor of the Amby race. The pathogenic population is a dynamic entity and is able to adapt under selection to overcome the resistance offered by different cultivars. Where differential cultivars have unknown or multigenic resistance, it is more difficult to identify races accurately. In the oat leaf rust system, most differentials have been found to contain several resistance genes. For instance, Ukraine possesses *Pc* 3c, 4c, 6c, and 9 while Saia has *Pc* 15, 16 and 17 (Simons *et al.*, 1978). Not only does this obscure information on the virulence of races, but the reactions are not always clear cut. The multigenic resistance interaction is poorly understood and so where effects such as residual or ghost resistance, synergistic or additive resistance, or other genetic disparities occur (ie. gene x genotype linkage), we are unable to account properly for the race genotype. Where the gene-for-gene relationship is not followed, such as with recessive resistance genes, resistance under dual genic control, modifiers or suppressors, or polygenic resistance, it becomes complicated to distinguish races from one another (Caten *et al.*, 1987). Consequently, while race typing in the past has given us some indication of the variability within the pathogen population with respects to virulence, it is likely we have not clearly identified all possible races. Although race 276 has been present in Australia for many years, race 276 infecting Panfive clearly has virulences different to that of the race 276 infecting Amby as seen on the additional differentials. It appears then, that race 276 comprises a number of races which are as yet unidentified due to the lack of appropriate differential cultivars.

Due to the complications involved in race typing using the old international differential set, Fleischmann and Baker (1971) have proposed a new differential set comprised of 10 isogenic (*Pc*) lines of oats containing single resistance genes transferred from *A. sterilis* (wild oats). Race typing will, in the future, be carried out using these lines to obtain a better understanding of the virulence patterns in the pathogen population. Panfive should also be included as a differential variety in all race identification work in this region as the existing supplementary differential lines do not allow identification of race 276 (45, 48).

Discrepancies in reactions on some of the additional differentials occurred between experiments. This was mostly due to difficulties when trying to determine whether an intermediate reaction ie. moderately resistant/susceptible reaction was either resistant or susceptible. A number of factors may influence the reactions including non-uniform experimental routines eg. differences in environmental conditions, (moisture status, temperature, light) host conditions (vigour, age) or pathogen conditions (inoculum level). Despite these few discrepancies, this additional information on the virulence of the isolate will be of value as distinction has been made between the two race 276 isolates, making breeders aware of the differences in the virulence patterns.

Acknowledgments

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References

Brown, J.F., and Kochman, J.K. (1973). A spore settling tower for uniform inoculation of leaves with rust urediniospores. *Aust. Plant Pathol. Soc. Newsletter* **2**, 26-7.

Caten, C.E. (1987). The concept of race in plant pathology. In *Populations of Plant Pathogens: their Dynamics and Genetics.* Wolfe, M.S. & Caten, C.E. eds. Blackwell Sci. Publ., Oxford.

Clifford, B.C. (1968). Relations of disease resistance mechanisms to pathogen dynamics in oat crown rust epidemiology. Ph.D. Thesis. Purdue University, Indiana.

Fleischmann, G., and Baker, R.H. (1971). Oat crown rust race differentiation: replacement of the standard differential varieties with a new set of single resistance gene lines derived from *Avena sterilis*. *Can. J. Bot.* **49**, 1433-7.

Heagle, A.S., and Moore, M.B. (1970). Some effects of moderate adult resistance to crown rust of oats. *Phytopathology* **60**, 461-6.

Irwin, J.A.G. (1991). Registration of Panfive oats. *Aust. J. Exp. Agric.* **31**, 867.

Johnson, R. (1984). A critical analysis of durable resistance. *Ann. Rev. Phytopathol.* **22**, 309-30.

Kochman, J.K., and Brown, J.F. (1975). Host and environmental effects on post-penetration development of *Puccinia graminis avenae* and *P. coronata avenae*. *Ann. Appl. Biol.* **81**, 33-41.

Kuhn, R.C., Ohm, H.W., and Shaner, F.E. (1978). Slow leaf-rusting resistance in wheat against twenty-two isolates of *Puccinia recondita*. *Phytopathology* **68**, 651-6.

Luke, H.H., Chapman, W.H. and Barnett, R.D. (1972). Horizontal resistance of Red Rustproof oats to crown rust. *Phytopathology* **62,** 414-417.

Luke, H.H., Barnett, R.D. and Pfahler, P.L. (1975). Inheritance of Horizontal resistance to crown rust in oats. *Phytopathology* **65**, 631-632.

Luke, H.H., Pfahler, P.L., and Barnett, R.D. (1981). Influence of disease severity and environmental conditions on low receptivity of oats to crown rust. *Plant Disease* **65**, 125-7.

Oates, M.D. (1989). Oat rust survey 1987-88. University of Sydney, Plant Breeding Institute, Castle Hill.

Parlevliet, J.E. (1979). Components of resistance that reduce the rate of epidemic development. *Ann. Rev. Phytopathol.* **17**, 203-22.

SAS Institute Inc. (1987). SAS/STAT Guide for Personal Computers, Version 6 Edition, Cary, North Carolina. pp.378.

Shands, H.L., and Forsberg, R.A. (1966). Registration of Lodi oats. *Crop Science* **6**, 389-90.

Simons, M.D. (1956). The genetic basis of the crown rust resistance of the oat variety Ascencao. *Phytopathology* **46**, 414-416.

Simons, M.D. (1966). Relationship of date of planting of oats to crown rust damage. *Phytopathology* **56**, 41-45.

Simons, M.D. (1970). Crown Rust of Oats and Grasses. Monograph No. 5. Amer. Phytopathol. Soc. USA.

Simons, M.D., Martens, J.W., McKenzie, R.I.H., Nishiyama, I., Sadanaga, K., Sebesta, J., and Thomas, H. (1978). Oats: A standardized system of nomenclature for genes and chromosomes and catalogue of genes governing characters. USDA Handbook No. **509**.

Simons, M.D. and Murphy, H.C. (1958). A comparison of certain combinations of oat varieties a crown rust differentials. *USDA Technical Bulletin. No.* **1112.**

Singleton, L.L., Moore, M.B., Wilcoxson, R.D., and Kernkamp, M.F. (1982). Evaluation of oat crown rust disease parameters and yield in moderately resistant cultivars. *Phytopathology* **72**, 538-540.

Sztejnberg, A., and Wahl, I. (1976). Mechanisms and stability of slow stem rusting resistance in *Avena sterilis*. *Phytopathology* **66**, 74-80.

Wahl, I., Wilcoxson, R.D., and Rowell, J.B. (1980). Slow rusting of wheat with stem rust detected in the glasshouse. *Plant Disease* **64**, 54-6.

Wilcoxson, R.D. (1984). Genetics of slow rusting in cereals. *Phytopathology* **71,** 989-993.

Zar, J.H. (1984). Biostatistical Analysis. 2nd ed. Prentice-Hall International Editions. London. pp.185-205.

Success in Achieving Objectives

1. *To select and release rust-resistant oat cultivars prior to identification of slow-rusting characteristics and release of slow-rusting varieties.*

It was envisaged that at the conclusion of the research, 4 slow-rusting cultivars would be selected for commercialisation. In the course of this research it was found that while slow-rusting cultivars had been reported in the literature, particularly from America, none of these cultivars were slow-rusting in the Australian environment.

In all, only two cultivars appeared to express PR. Panfive and 86QK-51 both appeared PR in the glasshouse when compared to the highly susceptible cultivar, Algerian. Panfive was infected with race 276 (45, 48) of Pca in the field in 1992. Consequently Panfive will be of limited use. To date, 86QK-51 has remained moderately resistant to the pathogen in the field and in the glasshouse is resistant to race 276 (45, 48) infecting Panfive. 86QK-51 will be used in future breeding work.

Several progeny from the Panfive x Ascencao cross and the Pan 4 x Panfive cross have been identified as resistant and have been given to Pacific Seeds Pty. Ltd. for commercialisation following further tests. In addition, 17 lines from the Pan 4 x Panfive cross were identified as resistant in glasshouse tests and these will also be handed over to Pacific Seeds Pty. Ltd.

2. *To screen oat cultivars in the glasshouse for slow-rusting characteristics*

Forty-four cultivars were considered for screening but results of field trials indicated that 30 of these were unsuitable. Of the 14 cultivars that were screened in the glasshouse, three cultivars (Andrew, Panfive and 86QK-51) appeared to express slow-rusting characteristics, although Andrew was found to be highly susceptible in the field.

3. *To investigate the effectiveness of slow-rusting cultivars in controlling crown rust in the field.*

Panfive has been grown in the field since 1981 and until 1992 had remained moderately resistant or resistant to Pca. However, a race of the pathogen has now appeared which is capable of overcoming the PR of this cultivar. Extensive field testing of 86QK-51 has not been carried out although this cultivar was moderately resistant in the field in 1992 and is resistant to race 276 (45, 48) infecting Panfive.

4. *To investigate the mechanisms (eg. incubation period, number of pustules, etc.) which contribute to slow-rusting.*

Components investigated included the latent period, infection efficiency, uredium density and size and spore production. Results of the glasshouse work indicated that uredium density gave the best indication of PR. Fewer (and smaller) uredia results in a reduction in the number of spores produced. This in turn will lead to a reduction in the rate of an epidemic.

Intellectual Property

Intellectual property in the form of the F_5 lines from the Panfive x Ascencao and Pan 4 x Panfive crosses have been developed.

Progress in Commercial Exploitation

Pacific Seeds Pty. Ltd. has entered into a 10 year contract from the date of commencement of commercial sales of any cultivars from the breeding lines which are produced as a result of the research. Pacific Seeds is now in possession of 9 resistant lines resulting from crosses between Panfive and Ascencao and Pan 4 and Panfive. Seventeen of the F_3 progeny from the Pan 4 x Panfive cross were found to be resistant to Pca in the glasshouse and will also be handed over to Pacific Seeds Pty. Ltd.

Impact on Meat and Livestock Industry

In Queensland, some 30% of cattle are grazed on oats during the winter and spring. In 1988/89, leaf rust epidemics reduced the grazing potential of oats by 50% resulting in an estimated $22 million loss for the cattle industry in Queensland. The use of resistant or partially resistant cultivars will significantly increase profits in the cattle industry.

Total Funding and MRC Contribution

Financial contributions from the MRC, including funds to commence major gene work.

Year	$
1989/90	53 521
1990/91	52 428
1991/92	80 428
Total	186 377

This is estimated to represent approximately 17% of the total project costs.

Conclusions and Recommendations

Although cultivars have been identified as slow rusting in America, eg. Ajax, Andrew, Portage, Brunker, these same cultivars, when grown in the field in Queensland, have proved to be susceptible to highly susceptible. Garry, a cultivar cited as slow-rusting in Australia, also failed to show adequate levels of resistance in the field.

Results of the glasshouse experiments indicated that the partial resistance of Panfive may be largely race non-specific. However, a race of Pca appeared in May/June 1992 which severely affected Panfive, overcoming the partial resistance of this cultivar. This isolate was identified as race 276 (45, 48). It therefore appears that Panfive expresses race specific partial resistance. Clearly then, specificity may limit the usefulness of this form of resistance. However, specificity may not always manifest itself as early as it did in the case of Panfive and some partially resistant cultivars may be of value for longer periods although this will only be realised in hindsight. As Johnson (1984) points out, durable resistance is "resistance that remains effective during its prolonged and widespread use in an environment favourable to the disease".

The glasshouse screening technique in which the primary leaf is inoculated and the uredium density assessed (in relation to a susceptible cultivar) provides an efficient means by which material can be quantitatively evaluated. This technique will also provide an efficient system whereby race specificity can be investigated. The ultimate test however, will always be in the field and while cultivars such as Panfive will be encountered, others with more durable resistance may be found.

The line, 86QK 51, while slightly more susceptible than Panfive, appears to express partial resistance and warrants further field testing. Having identified partially resistant cultivars, tests for race specificity need to be carried out. If the resistance appears race non-specific, attempts should, and have been made to incorporate this resistance into other agronomically desirable cultivars as new combinations of genes may condition a more durable resistance.

As described previously, Panfive has been crossed with Ascencao which expresses moderate resistance to many races including race 276 (45, 48) infecting Panfive. Several lines from this cross have been identified which express high levels of resistance. Similar attempts will be made with 86QK 51.

While there are obvious difficulties in detecting durable partially resistant cultivars, the search for them should continue. New resistance genes are continually being discovered which alone, or in conjunction with other resistance genes, may provide durable resistance, be it either partial or complete. The glasshouse screening technique developed has enabled the identification of partially resistant cultivars which can be used in future breeding work.

Media Coverage

There was considerable coverage of the problem of crown rust in oats in the rural press. An article in Focus on Beef 1990 which described the approach adopted in the slow-rusting work is appended.

Publications

Brake, V.M and Irwin, J.A.G. (1992). Partial resistance of oats to *Puccinia coronata* f. sp. *avenae*. *Aust. J. Agric. Res.* **43,** 1217-27.

Brake, V.M and Irwin, J.A.G. (1992). Partial resistance of oats to *Puccinia coronata* f. sp. *avenae*. General Sessions. Procedings of the 4th International Oat Conference. Oct 20-23, 1992. **3,** 33-35.

THE FIGHT AGAINST RUST IN OATS

By Peter Thompson, QDPI, Toowoomba

After several years of bad experiences with oats going "rusty", and not producing much feed, a lot of fatteners are having second thoughts about planting oats for feed this year.

Unfortunately there have been problems with oats' susceptibility to rust, however, things are looking a lot brighter. This is as a result of a fairly intensive oat selection programme by pasture agronomists, plant breeders and plant pathologists of the Department of Primary Industries over the last few years.

Their efforts, in conjunction with seed merchants, has meant that two new rust resistant varieties of oats will hopefully be commercially available in the 1991 season. One of these will be a Camellia type and the other more erect and similar to Minhafer.

As rust resistance in any plant usually breaks down as new rust strains develop, the resistance in these new varieties will not remain effective indefinitely. The DPI staff are well aware of this and it is expected that in the years ahead new rust resistant oat varieties will be released. These new varieties will also come from selections out of breeder lines from the USA. In the 1990 season, a short list of 30 introduced lines will be assessed at Gatton and Biloela research Stations and on the eastern Darling Downs.

These new lines look very promising. In fact there are so many good varieties in the new material that picking the best to release will be quite a hard job. Other research being conducted jointly by the Queensland Department of Primary Industries and University of Queensland and the Sydney University is looking at the possibility of selecting oats with slow rusting characteristics. This means that although the oats will not be fully resistant to rust, the disease will build up slowly and to a lesser extent that in susceptible varieties when ideal rust conditions prevail.

CURRENT OPTIONS

That is the good news but what do we do while we are waiting for these new varieties to become available?

One option is to plant Panorama 5 oats as it is the most leaf rust resistant commercially available oat variety. Bearing in mind what has already been mentioned about rust resistance breaking down, it does not mean that Panorama 5 is guaranteed rust resistant. Unfortunately there will only be limited quantities of this seed available to plant, so other strategies will be needed.

To try and avoid a rust problem we need to know the factors that are most likely to cause problems. These are:

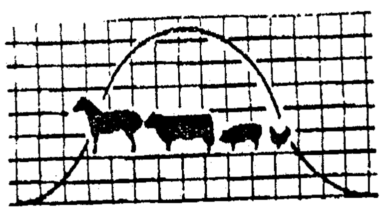
* susceptible species (in this case oats) and susceptible varieties within that species; and
* warm wet conditions.

The first strategy then is to avoid planting oats for as long as possible and preferably not before mid March.

If feed has to be planted before this time, only plant the prostrate late flowering oat varieties. First preference here would be for Algerian. However, as seed of this variety will be scarce, second options include Cooba, Camellia and Blackbutt. Having decided that oats has to be planted at this time, be prepared for the possibilities of it getting rusted or burnt off by hot weather.

After the middle of March until the first week in April the list is expanded to include the erect late flowering varieties such as Panorama 5, Minhafer, Garry and Stout. From April onwards you can plant grazing Triticales, Corvette or Grimmett Barley and Canary.

It needs to be stressed that the planting of other cereals early is not an option. Barley, wheat or triticale planted before April usually run up to head in May without producing much feed. Although winter wheat and winter barley varieties should not do this, the performance of varieties tested in Queensland has not been encouraging. It is possible these types planted early could suffer from other diseases such as stem rust, which would provide a build up of inoculum for later planted wheat and barley grain crops.



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Aust. J. Agric. Res., 1992, **43**, 1217–27

Partial Resistance of Oats to *P. coronata* f sp. *avenae*

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Abstract

Several oat cultivars (*Avena* sp.) were inoculated on the 1st, 2nd and 4th leaves with race 264 of *P. coronata* f. sp. *avenae* to characterize and determine components of partial resistance (slow rusting). Panfive was the only cultivar to exhibit partial resistance. It gave a moderately susceptible reaction but expressed a lower infection efficiency, fewer and smaller uredia, and a lower spore production compared to the susceptible cultivars Algerian and Sual for all three leaf ages tested. In the field this cultivar has consistently shown partial resistance.

Garry, a cultivar reported to be slow rusting but highly susceptible in the field in Queensland, expressed a significantly lower infection efficiency and uredium density than Algerian and Sual on the first leaf. Older leaves of Garry, however, did not show a significant reduction in the components of partial resistance when compared to Algerian and Sual.

Results suggested that uredium density gave the best indication of partial resistance across the three leaf ages tested for Panfive. A significant difference was present between uredium densities on upper and lower surfaces of the 4th leaf only for the susceptible and partially resistant cultivars. In general, the resistance of all cultivars tended to increase with an increase in leaf age.

Keywords: oats, *P.coronata*, partial resistance.

Introduction

Puccinia coronata Cda. f. sp. *avenae* Fraser & Led. (Pca) causes substantial losses in oat (*Avena* spp.) crops throughout the world. To reduce these losses, completely or near completely resistant cultivars have been deployed. However, owing to the variability of the pathogen, cultivars expressing this form of resistance have been of use for only short periods of time. Consequently attention is now being directed toward identifying plants which express partial resistance (PR). This form of resistance, which places less selection pressure on the pathogen population and slows the rate of epidemics, is often referred to as slow-rusting and has been investigated in relation to the rusts of wheat, barley, oats, maize and asparagus (Heagle and Moore 1970; Kochman and Brown 1975; Johnson and Wilcoxson 1978; Shaner *et al.* 1978; Martin *et al.* 1979; Rees *et al.* 1979; Luke *et al.* 1981; Osman-Ghani and Manners 1985; Johnson 1986; Zummo 1988; Hyde and Elahinia 1991).

Although partial or incomplete resistance is not necessarily stable or durable, there have been cases where this form of resistance has been long lasting, such

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as in wheats containing the *Sr2* gene, which provides incomplete resistance to *P. graminis*, and in the wheat cultivar Capelle-Desprez, which is incompletely resistant to *P. striiformis* (Johnson 1984).

Components found to be associated with the slow-rusting character include longer latent periods, a lower infection frequency, smaller uredia, shorter infectious periods and reduced sporulation (Heagle and Moore 1970; Ohm and Shaner 1976; Sztejnberg and Wahl 1976; Johnson and Wilcoxson 1978; Martin *et. al.* 1979; Wahl *et al.* 1980). Parlevliet (1979) used the term 'partial resistance' rather than slow rusting, when he defined PR as a 'form of incomplete resistance in which the spore production is reduced even though the host plants are susceptible to infection.' For the purpose of this paper, the term partial resistance will be adopted to refer to susceptible plants which express a reduction in most, if not all, of the components mentioned above when compared to a highly susceptible cultivar.

Owing to the great degree of variability that exists within the Pca population in Australia (Brouwer and Oates 1986), the deployment of partially resistant oat cultivars may provide a long-term solution in reducing the effects of rust epidemics. The cv. Panfive, which was recently registered in Australia, has consistently shown partial resistance to leaf rust in the field under both experimental and commercial conditions since 1981 and 1985 respectively (Irwin 1991). This genotype, when tested as CI 8456, had previously shown durable resistance to leaf rust in the buckthorn nursery at Minnesota over the period it was tested (1964–1967; D. D. Stuthman pers. commun.). Owing to the PR of Panfive, investigations were undertaken to develop a glasshouse assay which could be used to select for partially resistant plants. In doing so, the effect of leaf age on resistance components such as latent period, infection frequency, uredium size and spore production was studied to identify those components which gave the best indication of PR.

Materials and Methods

Cultivars Tested and Races of Pca Used

Three of the oat cultivars used in the experiment, Ascencao, Panfive and Sual, were selected for testing on the basis of their reaction to race 264 of Pca during a 1989 field trial conducted at the Queensland Wheat Research Institute, Toowoomba (Table 1). These cultivars generally exhibited moderately susceptible to moderately resistant reactions. Although cultivar Garry was susceptible in the field, it was included in the experiments, as it has been cited in the literature as a slow-rusting cultivar (Kochman and Brown 1975). In the experiment, Algerian and Saia were used to represent susceptible and resistant controls respectively.

Table 1. Field reactions and percentage of leaf tissue rusted for cultivars tested during 1989 at Toowoomba, Queensland

Plants were assessed on 23 June 1989, 73 days after sowing. R, resistant; MR, moderately resistant; MS, moderately susceptible; S, susceptible; VS, very susceptible

Cultivar	Reaction	% leaf rusted	Cultivar	Reaction	% leaf rusted
Algerian	VS	80	Panfive	MS	30
Ascencao	MS–MR	20	Saia	R–MR	10
Garry	VS	90	Sual	S	70

The most virulent race available to us, race 264 of Pca was used in the experiment. It has virulence on nine of the 10 international differential cultivars, plus additional virulences on two of the supplemental lines, *Pc39* and *Pc45* (Fleischmann and Baker 1971).

Growth of Plants and Inoculation Procedures

Seed of each of the cultivars was pregerminated for 24 h before being planted in U.C. mix (1 : 3 v : v peat : sand) in 12 cm diameter pots. Three replicate pots, each containing six seeds were planted per cultivar for each leaf age treatment. Seeds were oriented in the one direction in the pots to facilitate inoculation of the leaves. Plantings were staggered approximately a week apart to enable the simultaneous inoculation of three different aged leaves; the first or primary leaf and the 2nd and 4th leaves. The plants were grown prior to inoculation in a naturally illuminated temperature controlled cabinet maintained at $24°\pm2°$C.

Plants were inoculated by lying the appropriate leaves flat on a piece of cardboard, abaxial side up and held in place by two rubber bands. The plants were placed in a spore settling tower (Brown and Kochman 1973) and inoculated with 10 μg of uredospores of race 264 of Pca. The inoculum was fired into the tower using a modified air rifle and the baffle plate was removed after approximately 5 seconds and plants were then left in the tower for 6 min. This gave a deposition of 540 uredospores per cm^2 with a coefficient of variation of 27%. Following inoculation, plants were incubated overnight (20 to 22 hr) in a dew chamber at $21\pm1°$C.

The inoculated plants were then transferred to the temperature controlled cabinet as previously described and watered daily.

Resistance Components Assessed

Disease reaction was assessed 12 days after inoculation using the system described by Murphy (1935). The inoculated leaves were harvested a day later by severing at the axil and then preserving in 30 mL of deionized water to which had been added 3 mL of lactophenol cotton blue. Care was taken to minimize spore loss when harvesting.

Components measured included latent period, infection efficiency, uredium density and size and spore production.

Latent period was the time taken, in days, from inoculation until the first uredia ruptured the epidermis.

Infection efficiency was determined for each cultivar by dividing the number of uredia on the abaxial leaf surface by the mean number of spores deposited per cm^2. The deposition density for each run in the settling tower was determined by counting the number of spores deposited on water agar plates (five per run), which were placed at leaf height in the settling tower when the plants were inoculated.

Uredium density was determined by counting the number of uredia greater then 0·4 mm in length on the abaxial leaf surface and dividing by the leaf area which was obtained by using a planimeter. Uredium density was determined for both the abaxial and adaxial leaf surfaces for cultivars Algerian, Garry, Panfive and Sual for reasons explained in a later section.

Uredium size (mm^2) was determined by measuring the length and breadth of 20 randomly selected uredia per leaf. The formula for the area of an ellipse, $\frac{1}{4}\pi$ (length$\times$breadth), was then used to calculate the area of the uredia.

Spore production for each cultivar was obtained by shaking the bottles containing the freshly preserved leaves for 30 min on a mechanical shaker. The number of spores in the suspensions was determined for each leaf using a haemocytometer and the number of spores/cm^2 of leaf area was calculated.

Statistical Analyses

Analysis of the data was carried out by single or multiple analysis of variances or both, using the SAS computer program (1987). All analyses were tested at the $P < 0{\cdot}05$ level of significance. Comparisons involving five or less means (i.e. leaf age and leaf surface comparisons) were tested using the t-test while comparisons involving more than five means (i.e. most cultivar comparisons) were tested using the Student–Newman–Keuls test (Zar 1984).

Results

Reactions

Ascencao and Saia both expressed the highest levels of resistance, developing few uredia regardless of leaf age. All other cultivars (Algerian, Garry, Panfive and Sual) developed uredia of varying sizes (Table 2). Garry and Panfive were slightly more resistant than Algerian and Sual producing in general, medium-size uredia which were sometimes associated with small amounts of necrosis. Garry and Panfive were therefore assigned reactions of moderately resistant to moderately susceptible. Algerian and Sual were moderately susceptible to susceptible producing medium to large-sized uredia associated with chlorosis. In general, all cultivars tended to show slightly more resistance in the glasshouse than in the field (Table 1).

Table 2. Reactions of cultivars for each leaf age

HR, highly resistant; MR, moderately resistant; MS, moderately susceptible; S, susceptible

Cultivar	Reaction 1st leaf	2nd leaf	4th leaf	Cultivar	Reaction 1st leaf	2nd leaf	4th leaf
Algerian	MS–S	MS–S	MS	Panfive	MR	MR–MS	MR–MS
Ascencao	HR	HR	HR	Saia	HR	HR	HR
Garry	MR–MS	MR	MR–MS	Sual	MS	MS	MR–MS

Latent Period

Latent periods (days) did not vary with leaf age, except on the 4th leaves of the more resistant cultivars, Ascencao and Saia where uredia took one day longer to rupture than those on the 1st and 2nd leaves (Table 3).

Table 3. Latent periods for each cultivar/leaf age treatment

Cultivar	Latent periods (days) 1st leaf	2nd leaf	4th leaf	Cultivar	Latent periods (days) 1st leaf	2nd leaf	4th leaf
Algerian	6	6	6	Panfive	6	6	6
Ascencao	7	7	7–8	Saia	9	9	9–10
Garry	6	6	6	Sual	6	6	6

Infection Efficiency

A significant interaction ($P < 0\cdot05$) was present between cultivar and leaf age with respect to infection efficiency (IE).

Cultivar differences

On the 1st leaf, the IE of Panfive and Garry was significantly lower ($P < 0\cdot05$) than that of Sual and Algerian and significantly higher ($P < 0\cdot05$) than that of Ascencao and Saia. Similar results were obtained for the 2nd leaf. On the 4th leaf, the IE of Garry and Algerian was significantly greater ($P < 0\cdot05$) than that of Panfive, Ascencao and Saia (Table 4).

Table 4. Cultivar and leaf age differences in infection efficiency

Within columns, numbers followed by the same letter are not significantly different ($P < 0 \cdot 05$) l.s.d. across rows ($P < 0 \cdot 05$): Algerian, ns; Ascencao, 0·06; Garry, 0·34; Panfive, 0·31; Saia, ns; Sual, 0·38

Cultivar	Infection efficiency 1st leaf	2nd leaf	4th leaf	Cultivar	Infection efficiency 1st leaf	2nd leaf	4th leaf
Algerian	0·90a	1·11ab	0·67a	Panfive	0·35c	0·65c	0·09b
Ascencao	0·04b	0·16d	0·05b	Saia	0·01b	0·10d	0·004b
Garry	0·33c	0·80bc	0·73a	Sual	1·15d	1·18a	0·36ab

Leaf age differences

The IE of all cultivars except Algerian and Saia were significantly ($P < 0 \cdot 05$) different with respect to leaf age (Table 4). In general, IE increased on the 2nd leaf, but did not always differ significantly to that of the 1st and 4th leaves.

Uredium Density

A significant interaction ($P < 0 \cdot 05$) was present between leaf age and cultivar with respect to uredium density (number/cm^2).

Cultivar differences

On the 1st leaves, the uredium densities for cv. Panfive and Garry were significantly lower ($P < 0 \cdot 05$) than those of Algerian and Sual, but significantly greater ($P < 0 \cdot 05$) than those of Ascencao and Saia. On the 2nd leaf, Panfive, with a density of 22·40 uredia/cm^2 produced significantly fewer ($P < 0 \cdot 05$) uredia than Algerian, Garry and Sual, but significantly more ($P < 0 \cdot 05$) than Ascencao and Saia. An intermediate number of uredia were expressed by Garry and Panfive on the 4th leaf, differing significantly ($P < 0 \cdot 05$) not only to one another but to all other cultivars (Table 5).

Leaf age differences

The uredium density for each of the three leaf ages differed significantly ($P < 0 \cdot 05$) to one another for cultivars Algerian, Garry and Panfive. Ascencao and Sual each expressed significantly lower ($P < 0 \cdot 05$) uredium densities on the 4th leaf than on the 1st and 2nd leaves. Saia expressed a significantly greater density ($P < 0 \cdot 05$) on the 1st leaf than on the 2nd and 4th leaves (Table 5).

Table 5. Cultivar and leaf age differences in uredium density

Within columns, means followed by the same letter are not significantly different ($P < 0 \cdot 05$) l.s.d. across rows ($P < 0 \cdot 05$): Algerian, 7·41; Ascencao, 0·34; Garry, 9·38; Panfive, 8·07; Saia, 1·08; Sual, 6·93

Cultivar	Uredium density (/cm^2) 1st leaf	2nd leaf	4th leaf	Cultivar	Uredium density (/cm^2) 1st leaf	2nd leaf	4th leaf
Algerian	64·60a	47·20a	20·69a	Panfive	30·85c	22·40c	7·61d
Ascencao	5·45b	5·78b	0·75b	Saia	2·94b	0·39b	0·03b
Garry	29·29c	50·47a	13·83c	Sual	54·04d	52·79a	23·46a

During the collection of data for the experiment, it was noticed that uredium density appeared to be greater on the upper (uninoculated) leaf surface than the lower inoculated surface of the 4th leaf of the more susceptible cultivars i.e. Algerian, Garry, Panfive and Sual. Uredium densities were therefore recorded for the upper surface of each of the three leaf ages for each of these four cultivars. The data were then subjected to an analysis of variance to test for the interaction of cultivar by leaf age by leaf surface (upper and lower). Significant interactions were present between (1) leaf age and leaf surface, and between (2) cultivar and leaf age.

Leaf Age by Leaf Surface Interaction

Leaf surface differences

The only significant difference ($P < 0 \cdot 05$) present was on the 4th leaf where the upper surface exhibited a greater uredium density than the lower leaf surface (Table 6).

Table 6. Leaf age and leaf surface differences in uredium densities
l.s.d. within columns ($P < 0 \cdot 05$) 1st leaf, ns; 2nd leaf, ns; 4th leaf, 5·78
l.s.d. across rows ($P < 0 \cdot 05$): upper, 7·80; lower, 7·20

Leaf surface	Uredium density (/cm^2) 1st leaf	2nd leaf	4th leaf
Upper	44·96	43·38	28·79
Lower	48·39	40·28	15·92

Leaf age differences

Uredium densities decreased significantly ($P < 0 \cdot 05$) with an increase in leaf age particularly on the lower surface. On the upper surface, significantly lower densities ($P < 0 \cdot 05$) were produced only on the 4th leaf (Table 6).

Cultivar by Age Interaction

Cultivar differences

Based on uredium densities for the 1st leaf, Garry and Panfive expressed significantly lower ($P < 0 \cdot 05$) uredium densities than Algerian and Sual. On the 2nd leaf, Panfive expressed a significantly lower ($P < 0 \cdot 05$) uredium density than that of Algerian, Garry and Sual while on the 4th leaf, the uredium density for Panfive was significantly lower ($P < 0 \cdot 05$) than that of both Sual and Algerian but not Garry (Table 7).

Table 7. Cultivar and leaf age differences in uredium density (on both upper and lower leaf surfaces)
l.s.d. within columns ($P < 0 \cdot 05$): 1st leaf, 7·53; 2nd leaf, 7·55; 4th leaf, 8·22
l.s.d. across rows ($P < 0 \cdot 05$): Algerian, 8·60; Garry, 8·11; Panfive, 6·72; Sual, 7·51

Cultivar	Uredium density (/cm^2) 1st leaf	2nd leaf	4th leaf	Cultivar	Uredium density (/cm^2) 1st leaf	2nd leaf	4th leaf
Algerian	66·01	51·58	28·06	Panfive	27·47	22·77	11·81
Garry	31·03	46·22	20·10	Sual	55·56	49·67	28·15

Age differences

Uredium densities for each leaf age differed significantly ($P < 0 \cdot 05$) to one another for both Algerian and Garry while Panfive and Sual both expressed significantly lower ($P < 0 \cdot 05$) uredium densities on the 4th leaf compared with the 1st and 2nd leaves (Table 7).

Uredium Size

An interaction between leaf age and cultivar was present based on the data for uredium size (mm^2).

Cultivar differences

The only significant difference ($P < 0 \cdot 05$) present for the 1st leaf was that between Garry which expressed the largest uredia and Saia which expressed the smallest uredia. Similar results were obtained for uredium size for the 2nd leaf, although Garry and Saia also differed significantly ($P < 0 \cdot 05$) to all other cultivars. On the 4th leaf, Algerian produced significantly larger ($P < 0 \cdot 05$) uredia than all other cultivars except Sual (Table 8).

Table 8. Cultivar and leaf age differences in uredium size

Within columns, means followed by the same letter are not significantly different ($P < 0 \cdot 05$) l.s.d. across rows ($P < 0 \cdot 05$): Algerian, ns; Ascencao, 0·01; Garry, ns; Panfive, 0·02; Saia, 0·01; Sual, 0·03

	Uredium size (mm^2)				Uredium size (mm^2)		
Cultivar	1st leaf	2nd leaf	4th leaf	Cultivar	1st leaf	2nd leaf	4th leaf
Algerian	0·09ab	0·10a	0·10a	Panfive	0·07ab	0·09a	0·06bc
Ascencao	0·10ab	0·10a	0·05b	Saia	0·06b	0·06c	0·04b
Garry	0·19a	0·14b	0·06bc	Sual	0·15ab	0·11a	0·09ac

Age differences

Significant differences ($P < 0 \cdot 05$) in uredium size between leaf ages were present for Ascencao, Panfive, Saia and Sual (Table 8). Algerian was the only cultivar in which uredium size increased from the 1st to the 4th leaf.

Spore Production

An interaction was not present between leaf age and cultivar with respect to the number of spores/cm^2 leaf area, although significant results ($P < 0 \cdot 05$) were obtained for cultivar and leaf age separately.

Cultivar differences

Algerian and Sual which produced the largest number of spores/cm^2 leaf area differed significantly ($P < 0 \cdot 05$) to one another and to all other cultivars (Table 9).

Leaf age differences

The number of spores/cm^2 produced on the 1st and 2nd leaves were significantly greater ($P < 0 \cdot 05$) than those produced on the 4th leaf (Table 9).

Table 9. Cultivar differences and leaf age differences in the number of spores/cm^2 leaf area

Within columns, means followed by the same letter are not significantly different ($P < 0 \cdot 05$)

Spore numbers (/cm^2)			
Cultivar (averaged across leaves)		Leaf inoculated (averaged across cultivars)	
Algerian	57981a	1	32713
Ascencao	2982b	2	24757
Garry	20852b	4	13637
Panfive	20396b	l.s.d. ($P < 0 \cdot 05$)	10441
Saia	3145b		
Sual	38439c		

Discussion

The cv. Panfive expressed fewer and smaller uredia and produced fewer spores when compared with the highly susceptible cvv. Algerian and Sual for all three leaf ages tested. This relative reduction in the density and size of the uredia and spore production would contribute to a reduction in the rate of an epidemic and thus Panfive appears to express PR. This response reflects the moderate levels of disease severity observed on this cultivar when grown in the field in Queensland. Panfive was selected from a cross between Lodi and PI 267989 (*A. sterilis*) (Irwin 1991). Lodi was developed and selected in the 1950*s*, and expressed resistance to races 264 and 216 of Pca in addition to a number of other races (Shands and Forsberg 1966). PI 267989 contains at least one dominant gene (*Pc 36*) which confers resistance to races 203, 216, 264, 290 and 321 in America (Simons *et al.* 1978). Inheritance studies have shown that the PR of Panfive to race 264 is controlled by a single recessive gene (Martin, Brake and Irwin unpublished data). Past experience has shown that resistance conditioned by a single gene is usually short-lived. However, the durability of the resistance in Panfive cannot be forecasted, since the incomplete resistance afforded by the *Sr2* gene in wheat has proven to be effective against *P. graminis* for many years (Hare and McIntosh 1979).

The cv. Garry, reported by Kochman and Brown (1975) to be slow-rusting when inoculated with race 237 of Pca, did not consistently show a reduction in the resistance components measured in this study when inoculated with race 264. In the field in Queensland, Garry has been rated as very susceptible when inoculated with race 264 of Pca and unlikely to possess a degree of PR of any value.

Uredium density appeared to be the component which best differentiated between the cultivars for all three leaf ages tested, and this has been supported by previous studies involving comparisons of the first and second leaves using the same cultivars tested in this work (Brake and Irwin unpublished data). Uredium density has frequently been found to be an indicator of slow rusting (Ohm and Shaner 1976; Kuhn *et al.* 1978; Shaner, *et al.* 1978; Martin *et al.* 1979; Luke *et al.* 1981), and correlated with the area under the disease progress curve (Johnson 1986; Johnson and Wilcoxson 1978).

A long latent period, which has been found to be a good indicator of PR to leaf rust of barley (Parlevliet 1979) was not apparent from the work reported in this paper. A longer latent period is considered to be an important component of PR, as it reduces the time available for the pathogen to reproduce. Longer latent periods have been found to be involved in the slow rusting of barley, maize and wheat (Ohm and Shaner 1976; Parlevliet 1976; Kuhn *et al.* 1978; Neervoort and Parlevliet 1978; Shaner *et al.* 1978; Johnson and Wilcoxson 1979; Scott 1989). However long latent periods are not always associated with slow-rusting, as Sztejnberg and Wahl (1976), Pataky (1986) and Johnson (1986) have all reported that long latent periods were not involved in the slow-rusting of oats, maize and asparagus respectively. Shaner (1973) also reported that slow mildewing of wheat caused by *E. graminis* did not involve long latent periods. It is possible, however, that leaf age may have had an effect, as plant age has been found to affect latency (Parlevliet 1976; Osman-Ghani and Manners 1985; Johnson 1986).

Although uredium size has been reported as a component of the slow rusting character (Heagle and Moore 1970; Ohm and Shaner 1976; Johnson and Wilcoxson 1978; Martin *et al.* 1979), it was not effective in differentiating between the cultivars used in this experiment, particularly on the first and second leaves. Ascencao, for example, expressed relatively large uredia, particularly on the first two leaves, although their density was very low. Spore production (No./cm^2 leaf area) similarly did not effectively differentiate between the cultivars, although it did distinguish the highly susceptible cvv. Algerian and Sual from the remaining cultivars. Spore production expressed as the number of spores per uredium, per mm^2 of uredium and per cm^2 leaf area have been found to be indicators of slow-rusting in some host–pathogen relationships (Heagle and Moore 1970; Johnson and Wilcoxson 1978; Shaner *et al.* 1978; Osman-Ghani and Manners 1985; Hyde and Elahinia 1991). Apart from the high variability in our data, the failure of the spore production component to separate the cultivars may be due to the method by which spore production was measured (i.e. as spores/cm^2 leaf area). Shaner *et al.* (1978) and Johnson and Wilcoxson (1978) both found that significant differences between fast- and slow-rusting cultivars varied, depending on the method by which spore production was measured. Variations between results were also found by Hyde and Elahinia (1991). Further studies using the various methods of spore production should be carried out to determine what measure of this component gives the best indication of PR.

While adult plants were not inoculated either in the glasshouse or the field, to allow a comparison between the seedling and adult plant responses, the reactions of the cultivars in the field at Toowoomba tended to be reflected in the relative rankings of the cultivars in the glasshouse experiment. Those components which did not clearly separate the cultivars in the seedling stage, i.e. latent period, uredium size and spore production, may be expressed more clearly in the adult stage. It should be noted, however, that not all of the components measured may contribute to a reduction or delay in an epidemic.

One response of interest was the difference in uredium densities between the upper and lower leaf surface on the 4th but not the 1st or 2nd leaves of the susceptible cultivars. The marked reduction in density on the lower leaf surface of the 4th leaves may reflect a change in the anatomical structure of the leaves as the plant matures. It is possible that tissues on the lower surface develop secondary thickening with age, thus preventing the fungus from developing. Histological studies would be needed to verify this supposition.

Results of our experiment have indicated that the 2nd leaf of all cultivars expressed a greater infection efficiency than either the 1st or 4th leaves. This increase in susceptibility on the 2nd leaf was also present on some, but not all of the cultivars, with respect to uredium density and uredium size. Similar results have been obtained in a previous experiment comparing the response of the 1st and 2nd leaves of the same cultivars (Brake and Irwin, unpublished data). This tends to indicate that the physiology of the 2nd leaf differs somewhat from that of the 1st and 4th leaves. Nevertheless, the results have shown that the response of the 1st and 4th leaves reflect the response of the plants when grown in the field in Queensland. It is therefore envisaged that, by using the procedures reported in this paper, and measuring the uredium density on the 1st or 4th leaves, it would be feasible to identify partially resistant cultivars in the glasshouse. Further screening would then be required in the field to ensure the selection of agronomically desirable cultivars.

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References

Brouwer, J. B., and Oates, J. D. (1986). Regional variation of *Puccinia coronata avenae* in Australia and its implications for oat breeding. *Ann. Appl. Biol.* **109**, 269–77.

Brown, J. F., and Kochman, J. K. (1973). A spore settling tower for uniform inoculation of leaves with rust urediniospores. *Aust. Plant Pathol. Soc. Newsl.* **2**, 26–7.

Fleischmann, G., and Baker, R. H. (1971). Oat crown rust race differentiation: replacement of the standard differential varieties with a new set of single resistance gene lines derived from *Avena sterilis*. *Can. J. Bot.* **49**, 1433–7.

Hare, R. A., and McIntosh, R. A. (1979). Genetic and cytogenetic analysis of durable adult-plant resistance in 'Hope' and related cultivars to wheat rusts. *Z. Pflanzenzucht.* **83**, 350–67.

Heagle, A. S., and Moore, M. B. (1970). Some effects of moderate adult resistance to crown rust of oats. *Phytopathology* **60**, 461–6.

Hyde, P. M., and Elahinia, S. A. (1991). The expression of partial resistance to *Puccinia striiformis* in wheat. Effects on colony growth and spore production. *J. Phytopathol.* **129**, 203–9.

Irwin, J. A. G. (1991). Registration of Panfive oats. *Aust. J. Exp. Agric.* **31**, 867.

Johnson, D. A. (1986). Two components of slow-rusting in asparagus infected with *Puccinia asparagi*. *Phytopathology* **76**, 208–11.

Johnson, D. A., and Wilcoxson, R. D. (1978). Components of slow-rusting in barley infected with *Puccinia hordei*. *Phytopathology* **68**, 1470–4.

Johnson, D. A., and Wilcoxson, R. D. (1979). Inheritance of slow rusting of barley infected with *Puccinia hordei* and selection of latent period and number of uredia. *Phytopathology* **69**, 145–51.

Johnson, R. (1984). A critical analysis of durable resistance. *Annv. Rev. Phytopathol.* **22**, 309–30.

Kochman, J. K., and Brown, J. F. (1975). Host and environmental effects on post-penetration development of *Puccinia graminis avenae* and *P. coronata avenae*. *Ann. Appl. Biol.* **81**, 33–41.

Kuhn, R. C., Ohm, H. W., and Shaner, F. E. (1978). Slow leaf-rusting resistance in wheat against twenty-two isolates of *Puccinia recondita*. *Phytopathology* **68**, 651–6.

Luke, H. H., Pfahler, P. L., and Barnett, R. D. (1981). Influence of disease severity and environmental conditions on low receptivity of oats to crown rust. *Plant Disease* **65**, 125–7.

Martin, C. D., Miller, J. D., Busch, R. H., and Littlefield, L. J. (1979). Quantitation of slow rusting in seedling and adult spring wheat. *Can. J. Bot.* **57**, 1550–6.

Murphy, H. C. (1935). Physiologic specialization in *Puccinia coronata avenae*. U.S. Dept. Agric. Tech. Bull. No. 433, pp. 1–48.

Neervoort, W. J., and Parlevliet, J. E. (1978). Partial resistance of barley to leaf rust, *Puccinia hordei*. V. Analysis of the components of partial resistance in eight barley cultivars. *Euphytica* **27**, 33–9.

Ohm, J. W., and Shaner, G. E. (1976). Three components of slow leaf-rusting at different growth stages in wheat. *Phytopathology* **66**, 1356–60.

Osman-Ghani, N., and Manners, J. G. (1985). Components of partial resistance to *Puccinia striiformis* in barley. *Plant Pathol.* **34**, 75–82.

Parlevliet, J. E. (1976). Evaluation of the concept of horizontal resistance in the barley/*Puccinia hordei* host–pathogen relationship. *Phytopathology* **66**, 494–7.

Parlevliet, J. E. (1979). Components of resistance that reduce the rate of epidemic development. *Ann. Rev. Phytopathol.* **17**, 203–22.

Pataky, J. K. (1986). Partial rust resistance in sweet corn hybrid seedlings. *Phytopathology* **76**, 702–7.

Rees, R. G., Thompson, J. P., and Mayer, R. J. (1979). Slow rusting and tolerance to rusts in wheat. I. The progress and effects of epidemics of *Puccinia graminis tritici* in selected wheat cultivars. *Aust. J. Agric. Res.* **30**, 403–19.

SAS Institute Inc. (1987). SAS/STAT Guide for Personal Computers, Version 6 Edition, Cary, North Carolina. 378 pp.

Scott, G. E. (1989). Effect of genes with slow-rusting characteristics on southern corn rust in maize. *Plant Disease* **73**, 114–16.

Shands, H. L., and Forsberg, R. A. (1966). Registration of Lodi oats. *Crop Sci.* **6**, 389–90.

Shaner, G. (1973). Reduced infectability and inoculum production as factors of slow mildewing in knox wheat. *Phytopathology* **63**, 1307–11.

Shaner, G., Ohm, H. W., and Finney, R. E. (1978). Response of susceptible and slow leaf-rusting wheats to infection by *Puccinia recondita*. *Phytopathology* **68**, 471–5.

Simons, M. D., Martens, J. W., McKenzie, R. I. H., Nishiyama, I., Sadanaga, K., Sebesta, J., and Thomas, H. (1978). Oats: a standardized system of nomenclature for genes and chromosomes and catalogue of genes governing characters. USDA Handb. No. 509.

Sztejnberg, A., and Wahl, I. (1976). Mechanisms and stability of slow stem rusting resistance in *Avena sterilis*. *Phytopathology* **66**, 74–80.

Wahl, I., Wilcoxson, R. D., and Rowell, J. B. (1980). Slow rusting of wheat with stem rust detected in the glasshouse. *Plant Disease* **64**, 54–6.

Zar, J. H. (1984). 'Biostatistical Analysis.' 2nd Edn. (Prentice-Hall International Editions: London.) pp. 185–205.

Zummo, N. (1988). Components contributing to partial resistance in maize to *Puccinia polysora*. *Plant Disease* **72**, 157–60.

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